46857 – RPT01

Evaluation and Recommendation of Waste Form and Packaging for Disposition of the K East Basin North Loadout Pit Sludge

G. B. Mellinger
C. H. Delegard
A. J. Schmidt
G. J. Sevigny

January 2004

Prepared for Fluor Hanford and the U.S. Department of Energy
under Contract DE-AC06-76RL01830 and
Contract Release 16282-179, Amendment 1.

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

This report documents the recommendation by Pacific Northwest National Laboratory (PNNL) to Fluor Hanford regarding the treatment of K East North Loadout Pit (KE NLOP) sludge to produce contact-handled transuranic waste (CH-TRU) for disposal at the Waste Isolation Pilot Plant (WIPP) in New Mexico. This recommendation is supported, in part, by testing results performed on KE NLOP sludge collected by Fluor and provided to PNNL in December 2003.

The KE NLOP contains approximately 6.3 m^3 of material (as-settled) that consists primarily of sand from backflushing the K-East Basin water treatment system sand filter, with some contamination from spent nuclear fuel corrosion products. Based on the results of this study, PNNL recommends that this material be treated using Nochar Acid Bond®. The treated waste would be packaged in steel billet cans with slip lids using a "cross tape" closure. These cans would be placed in filtered plastic bags that would be loaded into Standard Pipe Overpacks (this is a WIPP "Authorized Payload Container" that consists of a 12-in.-diameter "pipe component" that is loaded into a 55-gallon drum). Two of these billet cans would be loaded into each Standard Pipe Overpack.

Of the options that were considered that would meet all requirements, this option would result in the production of approximately 35 to 60 percent more packages than if the sludge were grouted. However, treatment with Nochar would also result in a robust process that is less sensitive to processing variations than grout. This option also facilitates WIPP certification by Fluor, as well as rework or repackaging of the treated waste by Fluor in the unlikely event that this is required subsequent to delivery of the treated waste to Fluor. Also, Nochar has already been accepted for use by WIPP.

KE NLOP samples were received from Fluor in December 2003 and characterized and tested in accordance with the Fluor-approved *Bench-Scale Testing Plan to Demonstrate Production of WIPP-Acceptable KE NLOP Sludge Waste Forms at the 325 Building.* The characterization and testing completed in support of this study included measurements of physical properties such as sludge density and water content, radiochemical characterization, and limited gas-generation testing. Per the Test Plan, additional reports will be provided to Fluor on February 2, 2004, and March 31, 2004, that provide additional characterization and testing data. These data will provide "Acceptable Knowledge" for use by Fluor in the WIPP certification process, but will not impact the waste treatment/waste packaging configuration recommended in this report.

In developing this recommendation, three potential waste forms for treated KE NLOP sludge were considered:

- grout
- Nochar
- dewatered sludge.

Four waste-package configurations were considered:

- direct loading of the treated waste in 55-gallon drums

- direct loading of the treated waste in Standard Pipe Overpacks
- loading of the treated waste in billet cans that would be placed in vented plastic bags and then loaded in Standard Pipe Overpacks
- direct loading of the treated sludge in S200-B Shielded Pipe Overpacks

An essential element of the study was to identify the constraints that any recommended option would need to meet. These constraints were based on the WIPP CH-TRU waste-acceptance criteria, as well as requirements for acceptance of the treated waste by the Central Waste Complex. The key constraint was the requirement that the waste packages have a surface dose rate $\leq$200 mrem/h. Options that met the constraints were then evaluated based on four criteria:

- numbers of packages produced
- ease of rework
- schedule viability
- cost.

Acronyms

AEA	Alpha Energy Analysis
ASO	Analytical Services Operations
CH	contact handled
CWC	Central Waste Complex
DOE	U.S. Department of Energy
EPA	Environmental Protection Agency
FGE	fissile gram equivalent
GEA	gamma energy analysis
ICV	Inner Containment Vessel
IXM	ion exchange module
KE	K East Basin
LEPS	low-energy photon spectrometry
NLOP	North Loadout Pit
PNNL	Pacific Northwest National Laboratory
SPO	Standard Pipe Overpack
STP	standard temperature and pressure
SWB	Standard Waste Box
TDOP	Ten-Drum Overpack
TMU	Total Measurement Uncertainty
TRU	transuranic
TRUPACT-II	Transuranic Packaging Transporter-II
USQ	unreviewed safety question
VOC	volatile organic carbon
WIPP	Waste Isolation Pilot Plant
WSB	standard waste box

Acknowledgments

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Contents

Figures

Tables

1.0 Introduction

The purpose and scope of this report are provided below. Background information is included that is associated with the sludge accumulated in the North Loadout Pit (NLOP) in the K East (KE) Basin and the impetus for its near-term treatment for disposition.

1.1 Purpose

This report documents the alternative waste forms and packaging configurations considered for disposition of the sludge accumulated in the KE Basin NLOP. The recommended option is documented, including the bases for its selection. The final disposition of the waste will be as contact-handled (CH) transuranic (TRU) waste at the Waste Isolation Pilot Plant (WIPP) located near Carlsbad, New Mexico.

1.2 Scope

The scope of material considered under this report is limited to the sludge present within the KE NLOP main pit and transfer channel. The volume of sludge in this location, based on direct measurements of sludge depths made in 1994, is estimated to be 5.2 m^3 in the main pit and 1.1 m^3 in the transfer channel (Baker 2001). The estimated upper-bound volume of the sludge is 6.2 m^3 in the main pit and 1.3 m^3 in the transfer channel (Baker 2001). During sludge sampling in this pit in 1999, the depths of sludge were noted on the sampling tubes inserted into the sludge in both the main pit and transfer channel. Measurements in 1999 indicated good agreement with sludge depths measured in 1994 (Baker 2001).

The scope of this report includes the identification of constraints that must be met by any of the alternatives examined. A listing of the alternatives considered and justification for removal of specific alternatives from consideration is provided. A shortened list of alternatives is examined against criteria used to evaluate the benefits and detriments of each of these alternatives. Data from testing the considered waste forms are included as part of the evaluation of the alternatives. Conclusions and a preferred recommendation are presented.

1.3 Background

1.3.1 Facility and Sludge Information

The K Basins, built in the early 1950s, have been used to store irradiated reactor spent nuclear fuel underwater for over 30 years. Associated with the spent nuclear fuel is an accumulation of particulate debris referred to as sludge. Sludge is defined as any solid material in the basin that will pass through a screen with 0.64-cm (0.25-in.) openings. Sludge is found on the basin floors, in canisters, and in other areas of the K Basins, i.e., pits. Sludge is composed of irradiated nuclear fuel particles, fuel corrosion products, cladding, storage canister corrosion products, corrosion products from features in the basin pools (e.g., racks, pipes, sloughed-off concrete), beads lost from ion exchange modules, environmental debris (e.g., windblown sand, insects, pieces of vegetation), and various materials (e.g., sand filter media, hardware, plastic) accumulated through operation of the basins over the past 30 years.

One of the locations where sludge has accumulated is the NLOP in the KE Basin. The KE NLOP, also known as the Sandfilter Backwash Pit, is estimated to contain 6.3 m^3 of sludge (Baker 2001). This pit is isolated from the main-basin pool and contains backwash material from the original sandfilter added to the KE Basin for N Reactor fuel storage (the KE Reactor was active from the 1950s to the 1970s and then deactivated, and in 1975, the water-filled storage basin was converted for storage of spent N Reactor fuel). The source of the water filtered through this sandfilter is the skimmers located in each of the three bays of the main basin pool; under normal operation, water passes through the sandfilters and then into an ion exchange module (IXM) and back to the basin. Unlike the K West Basin, which was cleaned of sludge (Wahlen 1980), some unspecified amount of historic sludge remains in the KE Basin from its prior use before being converted for N Reactor spent-fuel storage.

1.3.2 Previous Sludge Characterization Data

Sludge in the KE NLOP has been sampled for characterization purposes twice in the past 10 years. These sampling campaigns (1993 and 1999) used methods that resulted in representative samples of the accumulated sludge material:

- 1993 Campaign. This campaign included a series of 13 core samples taken at random locations across the pit. The cores extended from the top surface of the sludge to the floor surface. These samples were taken in response to unreviewed safety question (USQ)/Safety concerns related to criticality questions over Pu buildup in the pit. Although the primary concern of this sampling was to address criticality, the general composition of the sludge was also measured (analyses were performed at both the 222-S and the Pacific Northwest National Laboratory [PNNL] 325 Building laboratories [Bechtold 1994; Warner and Harris 1994]). The depth of the accumulated sludge was also measured at that time for many positions, mapped, and the corresponding overall sludge volume in the pit estimated (Baker 2001). Selected results from the 1993 campaign are provided in Table 1.1. These results show that there is minimal difference in the composition of the sludge core samples taken at various locations in the NLOP.

- 1999 Campaign. This campaign included two core samples taken as part of an overall characterization effort performed for most of the stream sources for KE Basin sludge (Pitner 1999). The cores extended from the top surface of the sludge to the floor surface. These two core samples were taken from the deeper areas of sludge in the NLOP, one in the main pit and one in the transfer channel. The two samples were then combined in the laboratory to form one large composite sample (Sample FE-3). Full laboratory analyses were performed at the 222-S and PNNL 325 Building laboratories, and the results are provided in Table 1.2 and Table 1.3.[a]

- Gas-generation testing was performed using approximately 20 g of sample FE-3 to quantify the concentration of metallic uranium (Bryan et al. 2001). Based on this testing, FE-3 was estimated to contain 0.0013 wt% uranium metal (settled sludge basis). No quantifiable levels of fission-product gases were detected during the gas generation, which provides good assurance that the FE-3 sludge sample contained essentially no uranium metal.

(a) RB Baker and TL Welsh. "Laboratory Data from the Consolidated and Single Pull Core Sludge Sampling Campaigns" (Internal Flour Hanford Memo, 01-SNF/RBB-004, May 10, 2001).

Table 1.1. 1993 NLOP Sample Data from 222-S and PNNL 325 Laboratories, Key Radionuclides, Aluminum, and Iron

(Source of data: Warner and Harris, 1994)

Sample ID	Sample Type	Sample Location	Density 222-S g/mL	U-Laser 222-S mg/mL	Am-241 222-S µCi/mL (GEA)	Pu-239/240 222-S µCi/mL (AEA)	Cs-137 222-S µCi/mL (GEA)	Co-60 222-S µCi/mL (GEA)	Al 222-S mg/mL (ICP-AES)	Fe 222-S mg/mL (ICP-AES)	U Laser PNNL mg/mL	Am-241 PNNL µCi/mL (GEA)	Pu-239/240 PNNL µCi/mL (AEA)	Cs-137 PNNL µCi/mL (GEA)	Co-60 PNNL µCi/mL (GEA)	Al PNNL mg/mL (ICP-MS)	Fe PNNL mg/mL (ICP-MS)
03 S3059	Core	Main Floor	1.08	4.60		0.929			3.2	8.86	4.64	0.849		2.56	0.0972	3.13	8.83
04 S3059	Core	Main Floor	1.3	5.26	1.521	1.696	7.803	0.203	5.43	21.1	6.28	1.48		7.53	0.208	5.05	20.7
11 S3059	Core	Main Floor	1.31	5.95	0.856	1.019	22.06	0.192	7.49	19.1	6.45	0.805	1.00	21.6	0.181	7.47	20.1
02 S3062	Core	Main Floor	1.18	9.95	0.832	0.928	9.899	0.201	4.15	9.33	7.02	0.829		9.89	0.204	4	2.31
03 S3062	Core	Main Floor	1.23	8.25	0.876	1.046	7.06	0.236	4.48	11.4	6.04	0.867	1.15	6.71	0.23	4.39	2.7
04 S3062	Core	Main Floor	1.25	15.00	1.314	1.684	12.513	0.299	5.17	11.9	9.19	1.4		12.3	0.297	4.79	3.48
05 S3062	Core	Main Floor	1.48	7.92	0.866	1.307	8.966	0.192	4.02	6.79	4.57	0.897		8.67	0.189	3.8	1.32
06 S3062	Core	Main Floor	1.53	4.93	0.66	0.769	9.948	0.265	5.2	16	3.48	0.649		9.65	0.255	5.32	3.85
07 S3062	Up-Layer	Main Floor	1.06	7.39	1.689	1.885	6.639	0.148	3.6	6.59	6.38	1.85	2.11	6.44	0.149	3.58	2.51
08 S3062	Low-Layer	Main Floor	1.37	12.30	1.223	1.525	5.026	0.274	3.64	10.7	6.48	1.29	1.77	4.86	0.274	3.67	3.92
05 S3059	Core	Trans Chan	1.08	7.15	1.824	2.24	5.345	0.257	3.29	7.11	7.91	1.83		5.19	0.245	3.22	7.56
06 S3059	Core	Trans Chan	1.2	6.08	1.046	1.259	4.202	0.192	3.01	58.2	6.79	1.06	1.40	4.14	0.194	3.34	57.1
07 S3059	Core	Trans Chan	1.42	6.18	1.245	1.451	12.489		5.08	47.1	6.18	1.22		12.1	0.157	5.38	46.4
08 S3059	Core	Trans Chan	1.31	6.02	1.27	2.96	10.623	0.288	4.7	13.2	5.98	1.23		10.5	0.295	5.16	15.5
Mean - All Samples			1.27	7.64	1.17	1.48	9.43	0.23	4.46	17.67	6.24	1.16	1.49	8.72	0.21	4.45	14.02
Stnd Dev - All Samples			0.15	2.96	0.36	0.60	4.65	0.05	1.19	15.61	1.40	0.38	0.45	4.74	0.06	1.18	17.39
Rel % Stnd Dev - All Samples			11.53	38.80	30.46	40.31	49.37	20.68	26.65	88.32	22.48	32.65	30.59	54.37	27.15	26.59	124.05
Mean - Core Samples			1.28	7.27	1.12	1.44	10.08	0.23	4.60	19.17	6.21	1.09	1.18	9.24	0.21	4.59	15.82
Stnd Dev - Core Samples			0.14	2.87	0.35	0.63	4.78	0.04	1.23	16.43	1.52	0.35	0.20	4.95	0.06	1.23	18.24
Rel % Stnd Dev - Core Samples			11.14	39.52	31.29	44.06	47.37	18.11	26.80	85.67	24.52	31.72	17.08	53.56	26.70	26.79	115.28
Mean - All Main Floor			1.28	8.16	1.09	1.28	9.99	0.22	4.64	12.18	6.05	1.09	1.51	9.02	0.21	4.52	6.97
Stnd Dev - All Main Floor			0.15	3.40	0.36	0.39	5.03	0.05	1.25	4.99	1.57	0.39	0.52	5.20	0.06	1.25	7.36
Rel % Stnd Dev - All Main Floor			12.05	41.72	32.58	30.78	50.34	21.67	27.03	41.00	25.88	35.54	34.62	57.66	28.53	27.63	105.55
Mean - Transfer Channel			1.25	6.36	1.35	1.98	8.16	0.25	4.02	31.40	6.72	1.34	1.40	7.98	0.22	4.28	31.64
Stnd Dev - Transfer Channel			0.15	0.53	0.33	0.78	4.02	0.05	1.02	25.07	0.87	0.34	--	3.91	0.06	1.15	23.85
Rel % Stnd Dev - Transfer Channel			11.65	8.37	24.80	39.47	49.19	19.94	25.45	79.84	12.93	25.40	--	48.98	27.02	26.98	75.38

Table 1.2. Radionuclide Inventory in KE NLOP Sludge Sample FE-3

(Source: Baker and Welsh, 2001)

Isotope	Settled Sludge µCi/mL	Dry Sludge µCi/g
^{241}Am	2.78E+00	4.73E+00
^{237}Np	5.90E-04	1.00-03
^{238}Pu	5.40E-01	9.18E-01
^{239}Pu	2.27E+00	3.85E+00
^{240}Pu	1.24E+00	2.12E+00
^{241}Pu	6.68E+01	1.14E+02
^{242}Pu	6.00E-04	1.02E-03
^{60}Co	1.99E-01	3.38E-01
^{137}Cs	1.10E+01	1.87E+01
^{154}Eu	2.50E-01	4.25E-01
^{155}Eu	1.02E-01	1.73E-01
^{90}Sr	3.90E+00	6.63E+00
^{99}Tc	2.44E-03	4.14E-03
^{137m}Ba	9.90E+00	1.68E+01
^{90}Y	3.90E+00	6.63E+00
^{234}U	3.82E-03	6.49E-03
^{235}U	1.44E-04	2.45E-04
^{236}U	5.41E-04	9.21E-04
^{238}U	3.11E-03	5.29E-03

Table 1.3. Chemical Composition of KE NLOP Sludge Sample FE-3

(Source: Baker and Welsh, 2001)

Analyte	µg/mL Settled Sludge	µg/g Dry Sludge
Al-icp.a	5.81E+03	9.88E+03
Ba-icp.a	3.93E+01	6.68E+01
Be-icp.a	7.12E+01	1.21E+02
Ca-icp.a	4.82E+03	8.20E+03
Cd-icp.a	5.79E+01	9.85E+01
Cr-icp.a	6.15E+01	1.05E+02
Cu-icp.a	1.58E+02	2.69E+02
Fe-icp.a	1.98E+04	3.37E+04
Mg-icp.a	4.47E+02	7.60E+02
Mn-icp.a	2.37E+02	4.03E+02
Ni-icp.a	2.05E+01	3.49E+01
P.icp.a	1.83E+02	3.11E+02
Pb.icp.a	6.94E+01	1.18E+02
Pu-239.icpms	3.53E+01	6.00E+01
S.icp.a	1.33E+02	2.26E+02
Si.icp.a	9.03E+02	1.54E+03
Sr.icp.a	8.79E+00	1.50E+01
TIC	1.53E+03	2.60E+03
TOC	2.52E+03	4.29E+03
Ti.icp.a	7.70E+01	1.31E+02
U.phos	9.88E+03	1.68E+04
Zn.icp.a	2.06E+02	3.50E+02
Zr.icp.a	2.48E+01	4.22E+01
pH	8.34	
Density, g/cc	1.23	
g-dry/g-settled	0.478	

2.0 Constraints

Constraints are considered the requirements that must be met for each alternative waste-form and packaging configuration considered for disposition of the sludge accumulated in the KE Basin NLOP. Any alternative, in order to be evaluated as a viable option, must first be shown to meet specified constraints. The constraints are based on waste-acceptance criteria for storage at the Central Waste Complex (CWC), payload requirements for shipment in the Transuranic Packaging Transporter-II (TRUPACT-II), and waste-acceptance criteria for disposition of CH waste at the WIPP. The criteria listed in this section are not the complete set of criteria required for total compliance with each of these source documents. Only those criteria from each of these sources that were considered to potentially impact one or more of the alternatives considered are described below. For example, all containers must be appropriately labeled so that this criterion was not included; however, package weight limitations exist that could constrain one or more alternatives so that this criterion was included.

It is recognized that these criteria undergo change and could be modified to allow for acceptance of materials previously not included. However, this is generally a lengthy process relative to the time frame in which a decision will be made to select a recommended approach. Therefore, for the purpose of this evaluation, it was considered that these criteria apply as they currently exist.

The treated KE NLOP sludge waste-form and packaging configuration must comply with all requirements associated with storage at the CWC, transport in the TRUPACT-II, and disposal at WIPP (WIPP 2002, 2003a). Table 2.1 identifies those requirements that are considered to constrain one or more of the alternatives considered.

Table 2.1. Constraints Affecting KE NLOP Sludge Disposition Alternatives

Constraint		
Container/Packaging Properties		
Container Types	Only the following payload containers are authorized for shipment in the TRUPACT-II (see Appendix 2.1 of the TRAMPAC document): • 55-Gallon Drum • 100-Gallon Drum • Standard Waste Box (SWB) • Ten-Drum Overpack (TDOP).	TRAMPAC
	Only the following containers are authorized for disposal as CH-TRU at WIPP: • 55-Gallon Drums (either direct loaded or containing a pipe component) • SWBs, either direct loaded, or containing up to four directly loaded 55-gallon drums, or containing one bin • TDOPs, either containing up to 10 directly loaded 55-gallon drums, six 85-gallon drum overpacks, or one SWB.	WIPP CH-TRU WAC
Container Weights	Each payload container and payload assembly shall comply with the following weight limits: Container Weights • 547 pounds per standard pipe overpack (SPO) with 12-in.-diameter pipe component • 547 pounds per S200 pipe overpack • 1,000 pounds per 55-gallon drum.	TRAMPAC
Sealed Containers	Sealed containers that are greater than 4 L (nominal) are prohibited except for Waste Material Type II.2 packaged in a metal container; Waste Material Type II.2 in metal cans does not generate any flammable gas. For this evaluation, no sealed containers were allowed.	TRAMPAC
Filter Vents	Vents or other mechanisms to prevent pressurization of containers or generation of flammable or explosive concentrations of gases shall be installed on containers of newly generated transuranic waste at the time the waste is packaged (DOE M 435.1-1, Chapter III, L.1.b.).	HNF-EP-0063
	Each payload container to be transported in the TRUPACT-II, including all payload containers that are overpacked in other payload containers, shall have one or more filter vents that meet the TRAMPAC specifications. Plastic bags used as confinement layers shall meet the specifications and usage requirements of the TRAMPAC.	TRAMPAC

Table 2.1 (Contd)

Constraint		
Physical Properties		
Liquid Waste	Liquid waste is prohibited in the payload containers, except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 percent (volume) of the payload container.	TRAMPAC
	Liquid waste is prohibited at WIPP. Waste shall contain as little residual liquid as is reasonably achievable by pouring, pumping, and/or aspirating. Internal containers shall also contain no more than 1 inch or 2.5 cm in the bottom of the internal containers. The total residual liquid in any payload container shall not exceed 1 percent by volume of that payload container. If visual examination methods are used in lieu of radiography, then the detection of any liquids in non-transparent internal containers will be addressed by using the total volume of the internal container when determining the total volume of liquids within the payload container.	WIPP CH-TRU WAC
Chemical Properties		
Pyrophoric Materials	Pyrophoric radioactive materials shall be present only in small residual amounts (<1 percent [weight]) in payload containers. Radioactive pyrophorics in concentrations greater than 1 percent by weight and all nonradioactive pyrophorics shall be reacted (or oxidized) and/or otherwise rendered nonreactive before placement in the payload container.	TRAMPAC
	Pyrophoric radioactive materials shall be present only in small residual amounts (<1 percent by weight) in payload containers and shall be generally dispersed in the waste.	WIPP CH-TRU WAC
Radiological/Nuclear Properties		
Decay Heat	If heat generation from radiological decay in the waste package exceeds 3.5 watts per cubic meter (0.1 watt per cubic foot), the package must be evaluated to ensure that the heat does not affect the integrity of the container or surrounding containers in storage. This evaluation must be provided to and approved by the WMP acceptance organization.	HNF-EP-0063
Fissile Content	The fissile and fissionable-material content of a package is limited, dependent upon the container and its contents. For 55-gallon or larger steel drums where fissile material is contained in 20% or more of the container volume, the fissionable-material content is limited to 177 fissile gram equivalents (FGEs). For 55-gallon or larger steel drums where fissile material is contained in less than 20% of the container volume, the fissionable-material content is limited to 100 FGEs. Limits for other containers are provided in Appendix B of HNF-EP-0063.	HNF-EP-0063

Table 2.1 (Contd)

Constraint		
Radiological/Nuclear Properties		
	A payload container shall be acceptable for transport only if the ^{239}Pu fissile gram equivalent (FGE) plus two times the measurement error (i.e., two standard deviations) is less than or equal to 200 g for a 55-gallon drum, a SPO, and an S200 pipe overpack. Note: If a payload container will be overpacked, FGE limits apply only to the outermost payload container of the overpacked configuration.	TRAMPAC
Curie Content	Up to 35 DE-Ci per container are acceptable at the CWC as a routine shipment. Quantities up to 150 DE-Ci per container can be accepted, but must be evaluated to ensure compliance with facility inventory limits (HNF-SD-WM-ISB-007).	HNF-EP-0063
	S200 pipe overpack payloads shall meet the package specific curie limits in the TRAMPAC (see Appendices 2.3 and 2.4, respectively).	TRAMPAC
	TRU waste payload containers shall contain more than 100 nCi/g of alpha-emitting TRU isotopes with half-lives greater than 20 years. Without taking into consideration the Total Measurement Uncertainty (TMU), the TRU alpha-activity concentration for a payload container is determined by dividing the TRU alpha activity of the waste by the weight of the waste. The weight of the waste is the weight of the material placed into the payload container (i.e., the net weight of the container). The weight of the waste is typically determined by subtracting the tare weight of the payload container (including the weight of the rigid liner and any shielding external from the waste, if applicable) from the gross weight of the payload container.	WIPP CH-TRU WAC
	Plutonium-239 equivalent curie (PE-Ci) is limited for waste containers and packaging configurations • 55-gallon drum in good condition, direct load of all approved waste forms is limited to $\leq$80 ^{239}Pu PE-Ci. • 55-gallon drum in good condition, direct load of solidified/vitrified waste forms is limited to $\leq$1,800 ^{239}Pu PE-Ci. • 55-gallon drum in good condition, direct load of all approved waste forms is limited to $\leq$80 ^{239}Pu PE-Ci. Other waste containers and packaging configurations have other limits. Refer to WIPP CH-TRU WAC.	WIPP CH-TRU WAC
Radiation Dose Equivalent Rate	Waste packages shall not exceed 1 milliSievert per hour (100 millirem per hour) at 30 centimeters (1 foot) from the waste package.	HNF-EP-0063
	Waste packages shall not exceed 2 milliSieverts per hour (200 millirem per hour) at any point on the surface of the package.	HNF-EP-0063

Table 2.1 (Contd)

Constraint		
Gas-Generation Properties		
Hydrogen Generation	For any package containing water and/or organic substances that could radiolytically generate combustible gases, determination must be made by tests and measurements or by analysis of a representative package such that the following criterion is met over a period of time that is twice the expected shipment time: The hydrogen generated must be limited to a molar quantity that would be no more than 5 percent by volume of the innermost layer of confinement (or equivalent limits for other inflammable gases) if present at standard temperature and pressure (STP) (i.e., no more than 0.063 g-moles/ft^3 at 14.7 pounds per square inch absolute and 32°F). Compliance with this requirement can be achieved by assuring that decay heat limits for each payload container are not exceeded. Per discussions with WIPP personnel during their visit to Hanford on December 16, 2004, the appropriate decay heat limits are as follows: Grout – 0.8800 watt/package Dewatered Sludge – 0.2708 watt/package Nochar – 0.1035 watt/package It should be noted that decay heat limits are dependent on both the properties of the waste-form and packaging configuration; the above values are based on treated waste that is packaged in slip-lid cans that are placed within filtered bags in a SPO. These values will bound the decay heat limits for each of the three waste-form options (the other packaging configurations considered in this study—direct loading into a drum, SPO, or S200-B Pipe Overpack—would allow for higher heat limits).	TRAMPAC
VOCs	TRU wastes to be transported in the TRUPACT-II are restricted so that no flammable mixtures can occur in any layer of confinement during shipment. While the predominant flammable gas of concern is hydrogen, the presence of methane and flammable (gas/volatile organic carbons [VOCs]) VOCs is also limited along with hydrogen to ensure the absence of flammable VOC mixtures in TRU waste payloads. Only payload containers (analytical category or test category) that meet the flammable (gas/VOC) limits based on the determinations for compliance with the flammable (gas/VOC) limits are eligible for shipment in the TRUPACT-II. Under the analytical category, a conservative analysis is used to impose decay heat limits on individual payload containers to ensure that flammable (gas/VOC) limits are met. Specifically, flammable VOCs are restricted to less than or equal to 500 parts per million (ppm) in the payload container headspace (to ensure that their contribution to flammability is negligible)	TRAMPAC

Table 2.1 (Contd)

Constraint		
Gas-Generation Properties		
Pressure	The gases generated in the payload and released into the Inner Containment Vessel (ICV) cavity shall be controlled to maintain the pressure within the TRUPACT-II ICV cavity below the acceptable design pressure of 50 pounds per square inch gauge (psig). All payloads authorized for transport in the TRUPACT-II will comply with the design pressure limit for a 1-year period.	TRAMPAC

HNF-EP-0063, *Hanford Site Solid Waste Acceptance Criteria*, Rev. 9, Fluor Hanford Inc., Richland, Washington, September 2003.

TRAMPAC, *TRUPACT-II Authorized Methods for Payload Control*, Rev. 19c, Washington TRU Solutions, LLC, Carlsbad, New Mexico, April 2003.

WIPP CH-TRU WAC, DOE/WIPP-02-3122, *Contact-Handled Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, Rev 0.1, U. S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico, July 2002.

3.0 Alternatives Considered

The alternatives considered are based on a combination of the possible waste form for the KE NLOP sludge and the final packaging configuration for that waste form.

3.1 Preparations and Properties of Waste Forms

Based on assessments given in the Test Plan ("Bench-Scale Test Plan to Demonstrate Production of WIPP-Acceptable KE-NLOP Sludge Waste Forms at the 325 Building," December 2003), three KE NLOP waste forms were prepared to evaluate waste-form preparation methods and to understand the waste forms' performance and qualities. The names and general descriptions of the three waste forms are shown in Table 3.1.

Table 3.1. KE NLOP Waste Forms

Waste Form Name	Description
NLOP-Moist	~50 g of as-settled sludge, drained of liquid
NLOP-Gt	~50 g of as-settled sludge and ~25 g of supernatant solution, blended and cured in grout
NLOP-Nochar	~50 g of as-settled sludge and ~25 g of supernatant solution, blended with Nochar Acid Bond 660.

In the design of preparation methods for any KE NLOP waste form, consideration must be given to the physical and chemical properties of the KE NLOP sludge and its associated supernatant solution. These feed-waste properties are described in more detail in Appendices B, C, and D. The qualities of the feed waste bearing most strongly on waste-form preparation are summarized by the following observations:

- The sludge consists of quickly settling sand, a rusty-brown slow-settling floc, and interstitial and supernatant solution.
- In the sample collection and laboratory testing with liter-scale material quantities, the sand was observed to settle to the container bottom within 1 minute. In contrast, settling the floc to a steady final volume required days.
- In limited testing and observation, and consistent with expectation, the compaction of the floc increases with the floc depth. This means that the floc compaction, and hence settled-sludge density, expected in the 1.5-m-deep LDC (large diameter container) may be greater than the density of 1.24 g/mL observed in laboratory tests with settled sludge about 0.12 m deep.
- The uranium and the analyzed radionuclides (primarily consisting of ^{60}Co, ^{137}Cs, $^{239,240}Pu$, and ^{241}Am) partition overwhelmingly to the solid phase. Therefore, the low-activity interstitial and supernatant solution may practically be considered a pure diluent, contributing negligible activity to the total sludge. As a consequence, the addition or removal of the supernatant solution during sludge processing will correspondingly decrease or increase the activity concentrations in the total sludge.

Retrieval of the sludge (particularly the sand) from the LDC likely will require additional solution. As a starting point to model this situation for grouted and Nochar waste-form development, sludge and supernatant solution mixtures were tested using the settled sludge prepared from the composited KE NLOP samples (density 1.24 g/mL) and supernatant solution in an amount corresponding to 50 wt% of the settled-sludge mass. This produced a diluted sludge with a volume about 1.3-times higher than the starting settled sludge (and radionuclide concentration about 1.3 times lower). The diluted sludge therefore had a density of about 1.15 g/mL. In process application, the amount of additional water may be adjusted to accommodate material behavior or target waste-product loadings.

Descriptions of the tested waste-form preparation ratios and physical properties are shown in Table 3.2. For example, the volume increases or decreases (expansion factors) incurred in going from the settled sludge to the prepared waste form are given in Table 3.2. For example, the tests show that the drained sludge product, NLOP-Moist, is only about half (0.47) of the volume of the starting sludge. In contrast, the grouted and Nochar waste forms, which also included additional supernatant solution, added to the final waste-form volumes such that the grouted and Nochar product expansion factors were 2.45 and 1.82, respectively.

Table 3.2. KE NLOP Waste Form Properties

Parameter	Waste Form		
	NLOP-Moist	**NLOP-Gt**	**NLOP-Nochar**
Waste Composition			
KE NLOP settled sludge mass, g	52.87	50.40	53.83
KE NLOP settled sludge volume, mL	42.6	40.6	43.4
KE Basin supernatant solution, g	0	24.73	24.35
Total feed waste mass, g	52.87	75.13	78.18
Total feed waste volume, mL	42.6	65.4	67.8
Additive			
Portland Type I/II cement, g	--	112.00	--
Bentonite, g	--	6.60	--
Nochar Acid Bond 660, g	--	--	2.95
Property			
Final waste-form volume, mL	20	99.3	79 (packed) / 120 (loose)
Final waste-form mass, g	28.92	193.73	81.13
Final waste-form density, g/mL	1.45	1.95	1.03 (packed) / 0.68 (loose)
Expansion factor, settled sludge → final waste form	0.47	2.45[(a)]	1.82 (packed)[(b)] / 2.76 (loose)[(b)]
Expansion factor, sludge and supernate → final waste form	--	1.52	1.17 (packed) / 1.77 (loose)

(a) The expansion factors apply to the feed settled sludge for sludge plus supernatant water formulations; water (e.g., from supernatant solution) still required for grouted waste formulation.
(b) The expansion factors apply to the feed settled sludge for sludge plus supernatant water formulations; the actual expansion factors for sludge-only (supernatant-free) formulations likely are lower and approach 1.17 (packed) / 1.77 (loose). Testing is required to confirm this behavior.

The properties of the individual waste forms are described in the following sections of this report. Section 3.1.1 describes the properties of NLOP-Moist, the sludge form simply drained of associated liquid. Section 3.1.2 describes the grouted waste form NLOP-Gt. Section 3.1.3 describes the waste-form

NLOP-Nochar prepared using the Nochar "Acid Bond 660" water absorbent. Further detailed descriptions of the preparation and properties of the waste forms are provided in Appendix F.

3.1.1 Drained Waste-Form NLOP-Moist

The waste-form NLOP-Moist was prepared with the aim to obtain a concentrated (low-volume) waste that had no drainable liquid. In practice, a continuous cross-flow filter, batch-wise filter press, or screened well pump within a final waste package might be used to draw the drainable liquid from the KE NLOP sludge.

The waste form was prepared in the laboratory by weighing a representative aliquot of the KE NLOP settled sludge into a 50-mL plastic centrifuge cone, inverting the cone on a stack of filter papers, and allowing the free liquid to drain through the papers.

The filter papers prevented sludge solids from leaving the cone while acting as a wick to draw solution from the sludge where it could evaporate from the margins of the papers. The boat/filter/cone was kept in the inverted position for 2 days but seemed to be well-drained after 1 day. The centrifuge cone with drained solids was re-weighed after 2 days, and the volume of the tapped solids was measured to determine the final form density of 1.45 g/mL. The drained sludge waste-form NLOP-Moist is undergoing gas-generation testing.

3.1.2 Grouted Waste-Form NLOP-Gt

Consultation with technical experts, review of technical literature, and testing using simulated KE NLOP sludge and supernatant solution were done to develop grouted-waste formulations. The goals were to find a simple formulation producing a "workable" (e.g., readily mixed) slurry that would set under air-tight conditions and produce a solid form yielding no "bleed water" (free liquid) upon curing.

It was found that Portland Type I, II, or I/II cement is suitable as the cement component and that bleed water can be controlled with bentonite or attapulgite clay additives. Bentonite was selected for testing with KE NLOP sludge because it has been used in other waste formulations for WIPP.

Based on experience, a cement/water weight ratio of about 0.5 produces an easily mixed slurry in construction applications. However, this blend produces significant bleed water. Increasing the cement fraction produces slurries that are increasingly difficult to mix and still yield appreciable bleed water (note—the WIPP waste form must have no free liquid). Bentonite additions to 0.5 ratio water/cement slurries were tested for workability and free liquid in the set product. Consistencies that would hold a peak when the mixer was withdrawn, but were not so thick that they would ball-up, produced grouts that set under closed conditions and yielded no bleed water. The amount of bentonite added proved to be about 9 wt% of the Portland cement used.

The NLOP-Gt waste form was prepared by mixing KE NLOP settled sludge, supernatant solution in the amount of half of the weight of settled sludge, and Portland Type I/II cement in an amount equal to twice the mass of the water contained in the combined sludge and supernate. The cement/sludge/supernatant ingredients were mixed thoroughly until the mixture was homogeneous. While stirring continued, dry-powder bentonite was added with stirring. The amount of bentonite added in preparing the NLOP-Gt waste form was 6 wt% of the added cement, somewhat less than the 9 wt% used in simulant testing. Less bentonite was used because the mixture had reached the desired thickness, and further addition would have been less workable. The mixture was thick and would not pour but had to be transferred by spatula. In full-scale application, the Portland cement/bentonite dry ingredients would be dry blended beforehand, and the dry blend mixed with the KE NLOP sludge and supernatant.

The sealed NLOP-Gt product was cast into two vessels (the larger quantity for gas-generation testing). Neither showed any bleed water after mixing or after setting. The waste forms set to hardness within 1 day.

The grouted sludge waste form from NLOP-Gt is undergoing gas-generation testing.

3.1.3 Adsorbent Waste-Form NLOP-Nochar

Nochar Acid Bond 660 is a polyacrylic water sorbent in a dry fine granular powder form. Among other applications, it has been used to absorb aqueous solutions in wastes destined for WIPP. The dry Nochar granules, when added to water with stirring, are observed to swell over a period of 1 to 2 minutes. The volumetric swelling of the particles is dramatic and within the 1- to 2-minute period; the Nochar/water product becomes a gelled mass containing fine (~1-mm-diameter) lumps. A similar product based on low cross-linked polyacrylates used for moisture absorption in rad waste disposal includes "Quik-Solid," a similarly textured dry granular solid offered by Cetco (http://www.cetco.com/groups/ww/TDS/QuikSolid.pdf). Besides their applications in rad-waste disposal, polyacrylate granule/powders are used in disposable diapers.

Based on vendor literature (Nochar, Inc., www.nochar.com), Nochar solidification agents have been tested and proven in over 150 waste streams (including stabilization of TRU-containing aqueous/sludge waste streams for ultimate disposal to WIPP). Stability tests performed on Nochar include paint filter testing, freeze/thaw testing, vibration testing, and radiation stability testing (90 Mrad—gamma/cobalt source). Due to project time constraints (i.e., insufficient time for independent testing), the vendor information on Nochar stability and its acceptance by WIPP serve as the technical basis for judging the long-term stability for the Nochar/KE NLOP sludge waste form.

The Nochar addition absorbs the free liquid and allows the waste to achieve the criterion of having no drainable liquid. The Nochar capacity to absorb water is pH-dependent, according to manufacturer's guidance, with higher absorption found at higher pH. The pH of the KE NLOP settled sludge is about 8.3 and that of the supernatant liquid is about 7.5, well within the range of optimum applicability of Nochar Acid Bond 660.

Preliminary tests with simulated KE NLOP sludge having 50 wt% additional water (a sand-water mixture containing 21 wt% sand) were performed to understand Nochar behavior and judge the quantity of Nochar required to eliminate drainable liquid. The addition of about 6 wt% Nochar, with respect to water, or about 4.5 wt% Nochar, with respect to the total sludge-plus-water mass, was sufficient to form a gelled semi-solid of cooked Cream-of-Wheat consistency. The product had a bulk density of 1.03 g/mL.

The NLOP-Nochar waste form was prepared by mixing KE NLOP settled sludge, supernatant solution in the amount of half of the weight of settled sludge, and Nochar Acid Bond 660 in an amount equal to about 3.8 wt% of the sludge-plus-water mass. The ingredients were mixed by shaking. After shaking, the bottle was opened and the product observed. No free liquid was seen, and the contents had a gelled springy consistency but with much open volume (air space) caused by the mode of mixing that could not be decreased by tapping. The product was left overnight and no free liquid was seen. A further day of storage still showed no free liquid. The distribution of solids throughout the Nochar-bearing product seemed to be uniform, judging by the relatively even brown color. The total volume bulk density of the void-filled product was about 0.68 g/mL.

The mode of mixing of the Nochar with the KE NLOP sludge and supernatant thus strongly influences the density of the product waste form. The preferred mode of mixing will require further development. However, adding the sludge/supernatant mixture directly to a pre-measured dose Nochar Acid Bond 660 sorbent (or equivalent) seems to be the simplest method. The rate of addition and mixing must be balanced by the rate of water uptake by the sorbent to help ensure that the distribution of radioactivity in the sludge (present almost exclusively on the sludge solids) is uniform in the product matrix.

The product of the laboratory test mixture with genuine KE NLOP sludge, NLOP-Nochar, is undergoing gas-generation testing.

3.2 Waste-Package Configuration

Three waste-package configurations were considered in this study: 55-gallon drums, standard pipe overpacks (SPOs), and S200B Pipe Overpacks. All three of these waste-package configurations are Authorized Payload Containers for transport of CH-TRU to WIPP in the TRUPACT-II or HalfPACT transport cask. Summary descriptions of these packages are provided below. Additional detail is provided in Appendices 2.1, 2.2, and 2.4 of WIPP (2003a). General arrangement drawings for these packages are provided in Appendix 1.3.2 of WIPP (2003b).

3.2.1 55-Gallon Drum

The 55-gallon-drum body, lid, and bolt ring are constructed of steel. A gasket of tubular or foam styrenebutadiene is required for drum lid closure. The approximate dimensions of the 55-gallon drum are given in Table 3.3.

Table 3.3. 55-Gallon Drum Dimensions

Dimension	Approximate Measurement (inches)	
	Inside Dimension	Outside Dimension (OD)
Height	33 1/4	35
Diameter	22 ½	24

The drum must have a minimum of one filter vent. An optional, rigid, polyethylene liner and lid may be used inside the drum. If a lid is used with the liner, the liner lid must contain a 0.3-in. minimum diameter hole, or a filter with hydrogen release rates equivalent to or greater than the 0.3-in. minimum diameter hole. A double-lid drum with a filtered inner lid will be considered the same as a drum with a filtered inner confinement layer. Table 3.4 presents the 55-gallon drum construction materials. Figure 3.1 is a drawing of the 55-gallon drum. Table 3.5 specifies the weights associated with the 55-gallon drum.

Table 3.4. 55-Gallon Drum Materials of Construction

55-Gallon Drum Component	Material
Body, lid, and bolt ring	Steel
Rigid liner and liner lid (optional)	High-density polyethylene
Closure	Bolted ring
Gasket	Type I—Tubular styrene-butadiene, or equivalent
	Type II—Foam styrene-butadiene, or equivalent
Rolling hoops	3-rolled or swedged types

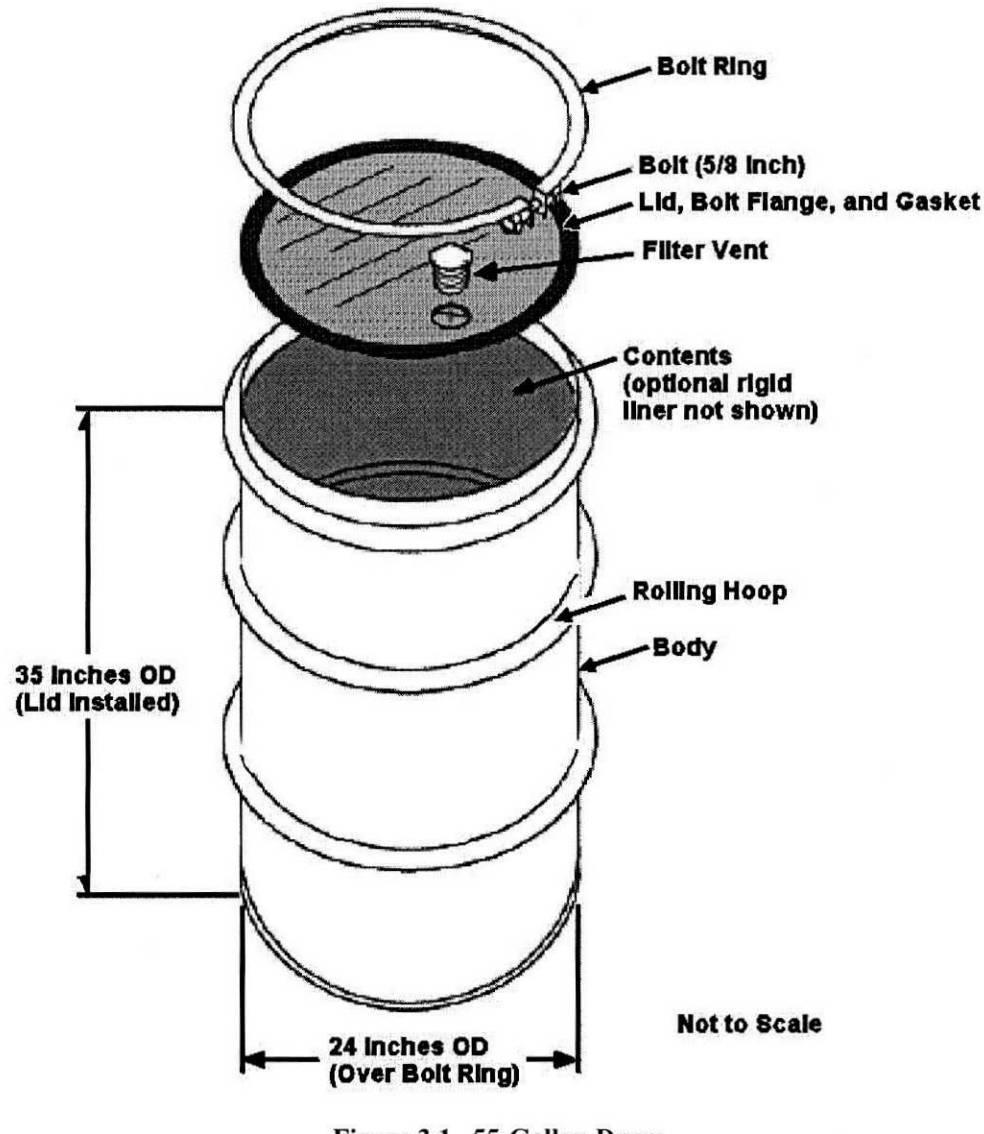

Figure 3.1. 55-Gallon Drum

Table 3.5. 55-Gallon Drum Weights

Component	Weight (lbs)	
	Approximate Empty	Maximum Gross
55-gallon drum	60	1,000
55-gallon drum with rigid liner and liner lid	77	1,000

CH-TRU waste may be directly loaded into a 55-gallon drum or may be loaded into a pipe component, which is then overpacked in a 55-gallon drum. The latter configuration constitutes an SPO, S100 pipe overpack, or S200 pipe overpack.

3.2.2 Standard Pipe Overpack

The SPO consists of a pipe component positioned by fiberboard/plywood dunnage within a 55-gallon drum with a rigid liner and lid (Figure 3.2). The pipe component is available in two sizes as specified in Table 3.6. The size considered in this analysis is the 12-inch pipe component.

Table 3.6. Pipe-Component Dimensions

Pipe-Component Size	Dimension	Maximum Measurement (in.)	Bolt Size (in.)	Number of Bolts	Minimum Bolted Flange Diameter (in.)
6-inch	Diameter	6.7 Outside Diameter	3/4	8	11
	Height	27.5 Overall			
12-inch	Diameter	12.8 Outside Diameter	7/8	12	16.3
	Height	27.5 Overall			

The pipe-component body, lid, and bolt flange are constructed of stainless steel. A butyl rubber or ethylene propylene O-ring is required for pipe-component closure. One or more bolts may have tamper-resistant heads and/or may have a thread-locking compound applied to the threads. As specified in Appendix 2.5, the pipe component and the overpacking 55-gallon drum each must have a minimum of one filter vent. Table 3.7 presents the pipe-component construction materials.

Table 3.8 specifies the weights associated with the pipe components. Table 3.9 specifies the weights associated with the SPO.

Table 3.7. Pipe-Component Materials of Construction

Component	Material
Body, lid, and bolt flange	Stainless steel
Closure	Bolted flange
Gasket	Butyl rubber or ethylene propylene O-ring

Table 3.8. Pipe-Component Weights

Pipe-Component Size	Pipe-Component Weight (lbs)	
	Maximum Contents	Maximum Gross
6-in.-diameter pipe component only	66	153
12-in.-diameter pipe component only	225	407

Table 3.9. Standard Pipe Overpack Weights

Size of Pipe Component Overpacked	Maximum Gross Weight (lbs)
6-in.-diameter pipe component overpacked in a 55-gallon drum	328
12-in.-diameter pipe component overpacked in a 55-gallon drum	547

Two applications of the SPO were considered in this analysis. One was direct loading of the treated waste in the SPO. The second was loading of the treated waste into "billet can" type containers that would then be loaded into the SPO. Steel billet cans with slip-fit lids would be used that would be placed in bags equipped with WIPP-compliant filters. The bagged cans containing the treated sludge would be loaded into the SPOs (two billet cans per SPO). The billet cans would be approximately 11 in. diameter by approximately 12 in. tall and have an internal volume of approximately 18 L.

3.2.3 S200-B Pipe Overpack

The S200 pipe overpack is a shielded version of the SPO described in Section 2.1.2. It consists of a gamma-shield insert located by rigid polyurethane foam dunnage inside a 12-in.-diameter pipe component positioned within a 55-gallon drum by means of fiberboard/plywood dunnage. A schematic of the S200 pipe overpack is shown in Figure 3.3. The 12-in.-diameter pipe component used in the S200 pipe overpack is identical to the 12-in.-diameter pipe component described for the SPO in Section 2.1.2. The 6-in.-diameter pipe component is not used in the S200 pipe overpack. The 12-in.-diameter pipe-component dimensions and materials of construction are specified in Table 3.10 and Table 3.11, respectively. The gamma-shield insert is a lead two-component assembly consisting of a cylindrical body with an integral bottom cap and a detachable lid. The shield insert is available in two sizes as specified in Table 3.10. The S200-B is the S200 pipe overpack considered in this analysis.

Table 3.10. Shield-Insert Nominal Dimensions

Size	Thickness (in.)	Inside Diameter (in.)	Inside Height (in.)	Outside Diameter (in.)	Outside Height (in.)
S200-A	1.000	8.125	8.125	10.125	10.625
S200-B	0.600	8.125	16.125	9.325	17.825

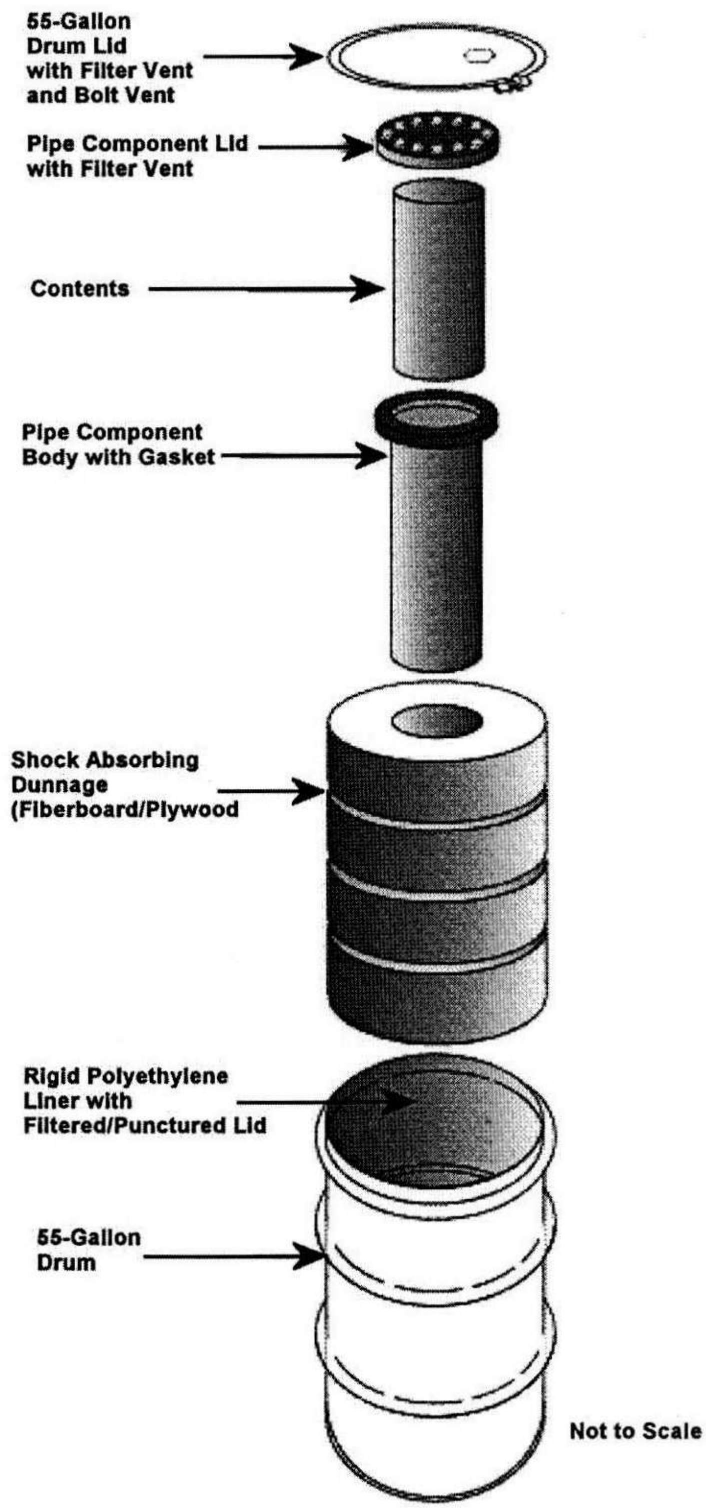

Figure 3.2. Standard Pipe Overpack

The shield-insert body, lid, and dunnage materials of construction are specified in Table 3.11.

Table 3.11. Shield-Insert Materials of Construction

Item	Material
Body, lid	Lead
Dunnage	Rigid polyurethane foam

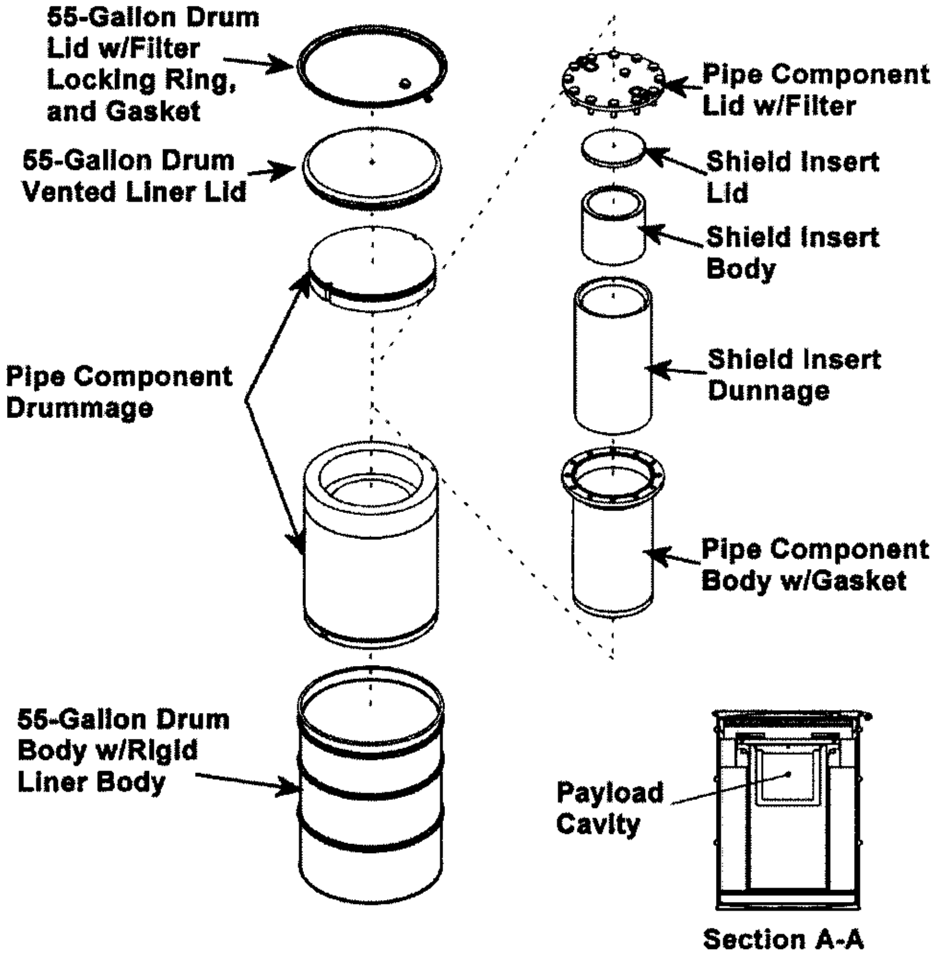

Figure 3.3. S200 Pipe Overpack

The maximum allowable weight of 12-in.-diameter pipe-component contents (shield insert assembly plus payload) is 225 lbs, and the maximum gross weight of the loaded 12-in.-diameter pipe component is 407 lbs, which are consistent with the specified 12-in.-diameter pipe-component weights. The maximum allowable gross weight of the loaded S200 pipe overpack is 547 lbs. Table 3.12 summarizes the nominal individual and maximum total weights associated with the shield-insert assembly components.

Table 3.12. 12-in. Pipe-Component Content Nominal Weights

Item	S200-A (lbs)	S200-B (lbs)
Shield-Insert Body	134	129
Shield-Insert Lid	43	27
Shield-Insert Dunnage	18	15
Payload	25	50
Total (Maximum)	225	225

4.0 Evaluation Criteria

The waste-form and waste-package configurations that are considered in this report are described in Section 4 of this report. All potential combinations of these waste-form and waste-package configurations must meet the acceptance criteria documented in Section 3 of this report to be considered for evaluation. Those combinations that meet the acceptance criteria have been evaluated and ranked based on the evaluation criteria provided below.

4.1 Number of Packages Produced

This criterion considers the estimated number of packages that would be produced for each combination of waste-form and package configuration that meet the acceptance criteria. Creating fewer packages requires acquiring, certifying, and shipping fewer containers to WIPP. A waste-form/waste-package alternative will rank higher if fewer waste packages would be produced.

4.2 Ease of Rework

Final certification of the packaged waste for acceptance at WIPP requires assaying every container of waste. Until a final waste-form and waste-package configuration is selected, it is not possible to determine the preferred method of performing assay of the containers. By allowing inner containers to be removed from the waste packages, it will allow greater flexibility in the approach to assaying the waste packages. Additionally, if individual waste forms or packages cannot meet certification requirements, it is advantageous to provide waste in a form that can be retrieved from the packaging in a contamination-controlled manner. This criterion considers the degree of difficulty associated with retrieving and/or reworking each of the waste-form/waste-package alternatives. A waste-form/waste-package alternative will rank higher if such retrieval or rework would be easier.

4.3 Schedule Viability

This criterion considers the impact that selection of a particular waste-form/waste-package configuration would have on the schedule for completing treatment of the KE NLOP sludge. Schedule impacts may include delays in the start of processing (due, for example, to procurement lead-time requirements), or delays in the completion of processing. The schedule viability will consider, for the waste-form/waste-packaging configurations, both the duration from authorization by Fluor Hanford to proceed until operations can be started and the duration of actual operations. Specifically, each waste-form/waste-packaging configuration will need to be able to demonstrate 1) compliance with 325 Building approval to start operations no later than March 15, 2004, 2) a minimum of 30 packages can be processed, packaged, and shipped to CWC no later than May 1, 2004, and 3) the balance of KE NLOP sludge processed and packaged no later than December 31, 2004. A waste-form/waste-package alternative will rank higher if it is more likely to achieve the listed dates above, which would make it less likely to encounter delays in being able to start processing and less likely to encounter delays during processing.

4.4 Cost

This criterion considers the cost to produce WIPP-acceptable waste forms at the 325 Building. The costs of the various waste-form/waste-package alternatives will be ranked relative to one-another. The costs developed are rough order-of-magnitude costs for relative comparison and should not be detailed estimates, nor should they be considered the total project costs. Costs examined do not consider retrieval of the KE NLOP sludge at K Basins because this cost is independent of the waste-form/waste-package alternative considered. Costs also do not consider the operational startup cost, which is estimated to be roughly equivalent, regardless of the packaging, and the waste-form alternative selected. Costs examined include 1) acquisition of equipment to perform the operation within the 325 Building, 2) acquisition of packaging systems for the waste, 3) acquisition of consumables including waste-former materials, 4) operational costs to create the packaged waste systems, and 5) the cost of demobilization and disposal of the system used to create the waste packages. A waste-form/waste-package alternative will rank higher if its cost is lower compared to the other alternatives.

5.0 Comparison of Alternatives

The alternative waste-form and waste-packaging options are shown in Table 5.1. This table also shows the settled sludge waste loadings, expressed as volume percent, that were considered for the KE NLOP sludge. These sludge waste loadings were based on radiochemical characterization of the sludge performed in support of this evaluation, shielding calculations, and the constraint that the surface dose rate of each package must not exceed 200 mrem/h. A simplified packaging configuration was used for the dose-rate calculation, but the simplifications will not significantly impact the shielding calculations.

Table 5.1. Waste-Form and Waste-Packaging Alternatives for KE NLOP

Packaging Alternatives	Waste Forms		
	Grout	**Nochar**	**Dewatering**
55-Gallon Drum	8%	7%	Not considered
Shielded Pipe Overpack	37%	23%	Not considered
Shielded Pipe Overpack with two billet cans	37%	29%	Not considered
S200-B Shielded Pipe Overpack	Not considered	Not considered	200%[a]

(a) The volume of a given quantity of dewatered sludge is half that of settled sludge. As a result, a container filled with dewatered sludge would contain twice the amount of sludge solids compared to the same container filled with settled sludge.

Some of the potential options were eliminated because dose-rate calculations showed that the dose rates would be too high; this applied to dewatered sludge packaged in drums or SPOs. Other potential options were eliminated because the limited internal volume of the package would result in an excessive number of packages; this applied to grout or Nochar packaged in S200-B Shielded Pipe Overpacks.

The following sections discuss how each of the remaining alternatives compares with the constraints presented in Section 2.0 and will also evaluate the alternatives with respect to the evaluation criteria presented in Section 3.0. A summary of the dose rates and WIPP drums produced for the alternatives above is shown in Table 5.2. The volumes of the packaging alternatives that were considered in this study are provided in Table 5.3.

Table 5.2. Summary of Dose Rates and Waste Packages Produced for Waste Form/Waste Package Alternatives

Vol% Settled Sludge (Percent)	Volume of Settled Sludge (Liters)	Density (g/cm^3)	Container Type	Estimated Maximum Dose Rate at Side of Package (m rem/h)	WIPP Process (#)	Form to Achieve Waste Loadings
200	22	1.5	S200-B	55	286	Dewatered
8	14	1.9	55-gal drum	180	445	Grout
5	8.8	1	55-gal drum	192	713	Nochar
37	16	1.9	SPO	150	396	Grout
37	13	1.9	SPO + two billet cans	120	473	Grout
23	10	1	SPO	160	630	Nochar
29	10	1	SPO + two billet cans	160	630	Nochar

Table 5.3. Volumes of Packaging Alternatives

	55-Gallon Drum	Standard Pipe Overpack	Standard Pipe Overpack with 2 billet cans	S200-B Shielded Pipe Overpack
Internal Volume	208	51	42	13.7
Working Volume	177	43	36	11

5.1 Grouted Waste Form Within 55-Gallon Drum

5.1.1 Description of Alternative

This waste form consists of a WIPP-certified drum and liner completely filled with grouted sludge. The grout formulation used was the same as the one demonstrated in the laboratory consisting of Portland cement, bentonite clay, water, and settled sludge. The settled sludge was assumed to be combined with an additional 50 volume percent water, and no additional dewatering steps were used in the process. The sludge and additives would be added directly to the container, mixed, and allowed to solidify.

A comparison of this alternative with the constraints presented in Section 2.0 is provided in Table 5.4. As the table shows, this alternative complies with all of the constraints for which information is currently available.

Table 5.4. Comparison of Grouted Waste Form Within 55-Gallon Drum with Treated-Waste Constraints (8 vol% settled sludge loading)

Constraint			Value for TBD alternative
Container/Packaging Properties			
Container Types	Only the following payload containers are authorized for shipment in the TRUPACT-II (see Appendix 2.1 of the TRAMPAC document): • 55-Gallon Drum • 100-Gallon Drum • Standard Waste Box (SWB) • Ten-Drum Overpack (TDOP).	TRAMPAC	55-Gallon Drum with rigid liner and liner lid
Container Weights	Each payload container and payload assembly shall comply with the following weight limits: <u>Container Weights</u> • 547 pounds per standard pipe overpack (SPO) with 12-in.-diameter pipe component • 547 pounds per S200 pipe overpack. • 1,000 pounds per 55-gallon drum.	TRAMPAC	820 lb (includes 77 lbs for drum and liner)
Sealed Containers	Sealed containers that are greater than 4 L (nominal) are prohibited except for Waste Material Type II.2 packaged in a metal container; Waste Material Type II.2 in metal cans does not generate any flammable gas. For this evaluation, no sealed containers will be allowed.	TRAMPAC	No sealed packages. WIPP-compliant filters will be used on drum and liner.
Filter Vents	Vents or other mechanisms to prevent pressurization of containers or generation of flammable or explosive concentrations of gases shall be installed on containers of newly-generated TRU waste at the time the waste is packaged (DOE M 435.1-1, Chapter III, L.1.b.).	HNF-EP-0063	
	Each payload container to be transported in the TRUPACT-II, including all payload containers that are overpacked in other payload containers, shall have one or more filter vents that meet the TRAMPAC specifications. Plastic bags used as confinement layers shall meet the specifications and usage requirements of the TRAMPAC.	TRAMPAC	

Table 5.4 (Contd)

Constraint			Value for TBD alternative
Physical Properties			
Liquid Waste	Liquid waste is prohibited in the payload containers, except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 percent (volume) of the payload container.	TRAMPAC	Observations and measurements performed during the bench-scale waste-form testing (Appendix F) demonstrated that no free liquids were released from waste form.
	Liquid waste is prohibited at WIPP. Waste shall contain as little residual liquid as is reasonably achievable by pouring, pumping, and/or aspirating. Internal containers shall also contain no more than 2.5 cm (1 inch) in the bottom of the internal containers. The total residual liquid in any payload container shall not exceed 1 percent by volume of that payload container. If visual examination methods are used in lieu of radiography, then the detection of any liquids in non-transparent internal containers will be addressed by using the total volume of the internal container when determining the total volume of liquids within the payload container.	WIPP CH-TRU WAC	
Chemical Properties			
Pyrophoric Materials	Pyrophoric radioactive materials shall be present only in small residual amounts (<1 percent [weight]) in payload containers. Radioactive pyrophorics in concentrations greater than 1 percent by weight and all nonradioactive pyrophorics shall be reacted (or oxidized) and/or otherwise rendered nonreactive before placement in the payload container.	TRAMPAC	Initial tests indicate that settled sludge contains <<1% U metal (Appendix E)
Radiological/Nuclear Properties			
Decay Heat	If heat generation from radiological decay in the waste package exceeds 3.5 watts per cubic meter (0.1 watt per cubic foot), the package must be evaluated to ensure that the heat does not affect the integrity of the container or surrounding containers in storage. This evaluation must be provided to and approved by the WMP acceptance organization.	HNF-EP-0063	0.011 W/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004][(a)])

(a) Schmidt and Baker. "Updated Design and Safety Basis Values for Physical Properties, Radionuclides, and Chemical Composition of Sludge in the KE Basin North Loadout Pit," PNNL letter report 46497-RPT02 (January 12, 2004), transmitted to WW Rutherford (FH) and JP Slaughter (NHC) by K. L. Silvers (PNNL) on January 12, 2004, via transmittal letter 46497-L03.

Table 5.4 (Contd)

Constraint			Value for TBD alternative
Radiological/Nuclear Properties			
Fissile Content	The fissile and fissionable-material content of a package is limited, dependent upon the container and its contents. For 55-gallon or larger steel drums where fissile material is contained in 20% or more of the container volume, the fissionable-material content is limited to 177 fissile gram equivalents (FGEs). For 55-gallon or larger steel drums where fissile material is contained in less than 20% of the container volume, the fissionable-material content is limited to 100 FGEs. Limits for other containers are provided in Appendix B of HNF-EP-0063.	HNF-EP-0063	3.7 g FGE/drum Based on KE NLOP Safety Basis Composition (Schmidt and Baker, 2004)[a]
	A payload container shall be acceptable for transport only if the ^{239}Pu FGE plus two times the measurement error (i.e., two standard deviations) is less than or equal to 200 grams for a 55-gallon drum, a SPO, and an S200 pipe overpack. Note: If a payload container will be overpacked, FGE limits apply only to the outermost payload container of the overpacked configuration.	TRAMPAC	
Curie Content	Up to 35 DE-Ci per container are acceptable at the CWC as a routine shipment. Quantities up to 150 DE-Ci per container can be accepted, but must be evaluated to ensure compliance with facility inventory limits (HNF-SD-WM-ISB-007).	HNF-EP-0063	Information related to this item will be provided in 2/2/04 report
	TRU waste payload containers shall contain more than 100 nCi/g of alpha-emitting TRU isotopes with half-lives greater than 20 years. Without taking into consideration the TMU, the TRU alpha activity concentration for a payload container is determined by dividing the TRU alpha activity of the waste by the weight of the waste. The weight of the waste is the weight of the material placed into the payload container (i.e., the net weight of the container). The weight of the waste is typically determined by subtracting the tare weight of the payload container (including the weight of the rigid liner and any shielding external from the waste, if applicable) from the gross weight of the payload container.	WIPP CH-TRU WAC	190 nCi/g [Based on total alpha analysis of KE NLOP Comp] [Safety Basin KE NLOP composition will give 3X higher value.]

(a) Schmidt and Baker. "Updated Design and Safety Basis Values for Physical Properties, Radionuclides, and Chemical Composition of Sludge in the KE Basin North Loadout Pit," PNNL letter report 46497-RPT02 (January 12, 2004), transmitted to WW Rutherford (FH) and JP Slaughter (NHC) by K. L. Silvers (PNNL) on January 12, 2004, via transmittal letter 46497-L03.

Table 5.4 (Contd)

Constraint			Value for TBD alternative
Radiological/Nuclear Properties			
Curie Content	Plutonium-239 equivalent curie (PE-Ci) is limited for waste containers and packaging configurations • 55-gallon drum in good condition, direct load of all approved waste forms is limited to ≤80 ^{239}Pu PE-Ci. • 55-gallon drum in good condition, direct load of solidified/vitrified waste forms is limited to ≤1,800 ^{239}Pu PE-Ci. • 55-gallon drum in good condition, direct load of all approved waste forms is limited to ≤80 ^{239}Pu PE-Ci. Other waste containers and packaging configurations have other limits. Refer to WIPP CH-TRU WAC.	WIPP CH-TRU WAC	Information related to this item will be provided in 2/2/04 report
Radiation Dose Equivalent Rate	Waste packages shall not exceed 1 milliSievert per hour (100 millirem per hour) at 30 cm (1 ft) from the waste package.	HNF-EP-0063	Information related to this item will be provided in 2/2/04 report
	Waste packages shall not exceed 2 milliSieverts per hour (200 millirem per hour) at any point on the surface of the package.	HNF-EP-0063	180 mrem/h [Based on modeling.]
Gas-Generation Properties			
Hydrogen Generation	For any package containing water and/or organic substances that could radiolytically generate combustible gases, a determination must be made by tests and measurements or by analysis of a representative package such that the following criterion is met over a period of time that is twice the expected shipment time: The hydrogen generated must be limited to a molar quantity that would be no more than 5 percent by volume of the innermost layer of confinement (or equivalent limits for other inflammable gases) if present at standard temperature and pressure (STP) (i.e., no more than 0.063 gram-moles/cubic foot at 14.7 pounds per square inch absolute and 32°F). Compliance with this requirement can be achieved by assuring that decay heat limits for each payload container are not exceeded. Per discussions with WIPP personnel during their visit to Hanford on December 16, 2004, the appropriate decay heat limits are as follows: Grout – 0.8800 watt/package Dewatered Sludge – 0.2708 watt/package Nochar – 0.1035 watt/package	TRAMPAC	0.011 W/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004]) [Appendix E discusses hydrogen generation from chemical reactions.]

Table 5.4 (Contd)

Constraint			Value for TBD alternative
Gas-Generation Properties			
Hydrogen Generation	It should be noted that decay heat limits are dependent on the properties of the waste-form and packaging configuration; the above values are based on treated waste that is packaged in slip-lid cans that are placed within filtered bags in a SPO. These values will bound the decay heat limits for each of the three waste-form options (the other packaging configurations considered in this study—direct loading into a drum, SPO, or S200-B Pipe Overpack—would allow for higher heat limits).	TRAMPAC	0.011 W/drum (Based on KE NLOP Safety Basis Composition [Schmidt & Baker, 2004]). Appendix E discusses hydrogen generation from chemical reactions.
VOCs	TRU wastes to be transported in the TRUPACT-II are restricted so that no flammable mixtures can occur in any layer of confinement during shipment. While the predominant flammable gas of concern is hydrogen, the presence of methane and flammable VOCs is also limited along with hydrogen to ensure the absence of flammable (gas/VOC) mixtures in TRU waste payloads. Only payload containers (analytical category or test category) that meet the flammable (gas/VOC) limits based on the determinations for compliance with the flammable (gas/VOC) limits are eligible for shipment in the TRUPACT-II. Under the analytical category, a conservative analysis is used to impose decay-heat limits on individual payload containers to ensure that flammable (gas/VOC) limits are met. Specifically, flammable VOCs are restricted to less than or equal to 500 parts per million (ppm) in the payload container headspace (to ensure that their contribution to flammability is negligible)	TRAMPAC	Information related to this item will be provided in 3/31/04 report.
Pressure	The gases generated in the payload and released into the Inner Containment Vessel (ICV) cavity shall be controlled to maintain the pressure within the TRUPACT-II ICV cavity below the acceptable design pressure of 50 pounds per square inch gauge (psig). All payloads authorized for transport in the TRUPACT-II will comply with the design pressure limit for a 1-year period.	TRAMPAC	Information related to this item will be provided in 3/31/04 report.

HNF-EP-0063, *Hanford Site Solid Waste Acceptance Criteria*, Rev. 9, Fluor Hanford Inc., Richland, Washington, September 2003.

TRAMPAC, *TRUPACT-II Authorized Methods for Payload Control*, Rev. 19c, Washington TRU Solutions, LLC, Carlsbad, New Mexico, April 2003.

WIPP CH-TRU WAC, DOE/WIPP-02-3122, *Contact-Handled Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, Rev 0.1, U. S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico, July 2002.

5.1.2 Evaluation with Respect to Evaluation Criteria

5.1.2.1 Number of Packages Produced

The estimated number of packages for a grouted drum is limited by dose rate and is estimated to be 445 with 14 L of settled sludge per drum. The dose rate target is 150 mrem/h, and the quantity of settled sludge per drum was adjusted to obtain a calculated dose rate of approximately 150 mrem/h. The WIPP limit is 200 mrem/h minus the uncertainties in the measurements. With only 14 L of sludge in the drum, the package does not approach any of the other WIPP limits, except the total weight. The density observed in the laboratory was slightly above 1.9, so the grouted drum weight is about 370 kg and does not exceed the WIPP limit of 454 kg.

5.1.2.2 Ease of Rework

A grouted drum would be very difficult to rework.

5.1.2.3 Schedule Viability

The additional number of containers over other options increases the risk to the solidification schedule, although the schedule viability is not significantly affected by any of the packaging alternatives

5.1.2.4 Cost

Grout materials are inexpensive, and the equipment needed to produce the waste would not add significantly to the overall cost. The grout required and the number of containers required would be similar for the filling grouted overpack containers and therefore is considered to have a slightly lower cost since the overpacks themselves will add cost to the grouted overpacks.

5.2 Grouted Waste Form in Standard Pipe Overpack Container Packaged Within 55-Gallon Drum

5.2.1 Description of Alternative

This waste form consists of a WIPP-certified overpack completely filled with grouted sludge. As an alternative, inner billet containers would be filled, bagged, and placed within the overpack container and the accompanying drum. The billet cans would be sized to allow two in a standard pipe overpack. The grout formulation used was the same as the one demonstrated in the laboratory, consisting of Portland cement, bentonite clay, water, and settled sludge. The settled sludge was assumed to be combined with an additional 50 volume percent water, and no additional dewatering steps were used in the process. The sludge and additives would be added directly to the overpack or billet can, mixed, and allowed to solidify.

A comparison of this alternative with the constraints presented in Section 2.0 is provided in Table 5.5. As the table shows, this alternative complies with all of the constraints for which information is currently available.

Table 5.5. Comparison of Grouted Waste Form Within Pipe Overpack Container Packaged Within 55-Gallon Drum with Treated-Waste Constraints (37 vol% settled sludge loading)

Constraint			Value for TBD alternative
Container/Packaging Properties			
Container Types	Only the following payload containers are authorized for shipment in the TRUPACT-II (see Appendix 2.1 of the TRAMPAC document): • 55-Gallon Drum • 100-Gallon Drum • Standard Waste Box (SWB) • Ten-Drum Overpack (TDOP).	TRAMPAC	SPO within a 55-gallon drum
	Only the following containers are authorized for disposal as CH-TRU at WIPP: • 55-Gallon Drums (either direct loaded or containing a pipe component) • SWBs, either direct loaded, or containing up to four direct loaded 55-gallon drums, or containing one bin • TDOPs, either containing up to 10 directly loaded 55-gallon drums, six 85-gallon drum overpacks, or one SWB.	WIPP CH-TRU WAC	
Container Weights	Each payload container and payload assembly shall comply with the following weight limits: <u>Container Weights</u> • 547 pounds per SPO with 12-in.-diameter pipe component • 547 pounds per S200 pipe overpack • 1,000 pounds per 55-gallon drum.	TRAMPAC	500 lb (includes 332 lb for pipe component and drum)
Sealed Containers	Sealed containers that are greater than 4 L (nominal) are prohibited except for Waste Material Type II.2 packaged in a metal container; waste material Type II.2 in metal cans does not generate any flammable gas. For this evaluation, no sealed containers will be allowed.	TRAMPAC	No sealed packages. WIPP-compliant filters will be used on drum and pipe component. For suboptions using billet cans, the can will be cross-taped and placed in vented (filtered) bags.
Filter Vents	Vents or other mechanisms to prevent pressurization of containers or generation of flammable or explosive concentrations of gases shall be installed on containers of newly generated TRU waste at the time the waste is packaged (DOE M 435.1-1, Chapter III, L.1.b.).	HNF-EP-0063	
	Each payload container to be transported in the TRUPACT-II, including all payload containers that are overpacked in other payload containers, shall have one or more filter vents that meet the TRAMPAC specifications. Plastic bags used as confinement layers shall meet the specifications and usage requirements of the TRAMPAC.	TRAMPAC	

Table 5.5 (Contd)

Constraint			Value for TBD alternative
	Physical Properties		
Liquid Waste	Liquid waste is prohibited in the payload containers, except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 percent (volume) of the payload container.	TRAMPAC	Observations and measurements performed during the bench-scale waste-form testing (Appendix F) demonstrated that no free liquids were released from the waste form.
	Liquid waste is prohibited at WIPP. Waste shall contain as little residual liquid as is reasonably achievable by pouring, pumping, and/or aspirating. Internal containers shall also contain no more than 2.5 cm (1 in.) in the bottom of the internal containers. The total residual liquid in any payload container shall not exceed 1 percent by volume of that payload container. If visual examination methods are used in lieu of radiography, then the detection of any liquids in non-transparent internal containers will be addressed by using the total volume of the internal container when determining the total volume of liquids within the payload container.	WIPP CH-TRU WAC	
	Chemical Properties		
Pyrophoric Materials	Pyrophoric radioactive materials shall be present only in small residual amounts (<1 percent [weight]) in payload containers. Radioactive pyrophorics in concentrations greater than 1 percent by weight and all nonradioactive pyrophorics shall be reacted (or oxidized) and/or otherwise rendered nonreactive before placement in the payload container.	TRAMPAC	Initial tests indicate that settled sludge contains <<1% U metal (Appendix E)
	Pyrophoric radioactive materials shall be present only in small residual amounts (<1 percent by weight) in payload containers and shall be generally dispersed in the waste.	WIPP CH-TRU WAC	
	Radiological/Nuclear Properties		
Decay Heat	If heat generation from radiological decay in the waste package exceeds 3.5 watts per cubic meter (0.1 watt per cubic foot), the package must be evaluated to ensure that the heat does not affect the integrity of the container or surrounding containers in storage. This evaluation must be provided to and approved by the WMP acceptance organization.	HNF-EP-0063	0.012 W/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004])
Fissile Content	The fissile and fissionable-material content of a package is limited dependent upon the container and its contents. For 55-gallon or larger steel drums where fissile material is contained in 20% or more of the container volume, the fissionable-material content is limited to 177 fissile gram equivalents (FGEs). For 55-gallon or larger steel drums where fissile material is contained in less than 20% of the container volume, the fissionable-material content is limited to 100 FGEs. Limits for other containers are provided in Appendix B of HNF-EP-0063.	HNF-EP-0063	4.2 g FGE/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004]).

Table 5.5 (Contd)

Constraint			Value for TBD alternative
Radiological/Nuclear Properties			
Fissile Content	A payload container shall be acceptable for transport only if the ^{239}Pu fissile gram equivalent (FGE) plus two times the measurement error (i.e., two standard deviations) is less than or equal to 200 g for a 55-gallon drum, a SPO, and an S200 pipe overpack. Note: If a payload container will be overpacked, FGE limits apply only to the outermost payload container of the overpacked configuration.	TRAMPAC	4.2 g FGE/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004])
Curie Content	Up to 35 DE-Ci per container are acceptable at the CWC as a routine shipment. Quantities up to 150 DE-Ci per container can be accepted, but must be evaluated to ensure compliance with facility inventory limits (HNF-SD-WM-ISB-007).	HNF-EP-0063	Information related to this item will be provided in 2/2/04 report.
	TRU waste payload containers shall contain more than 100 nCi/g of alpha-emitting TRU isotopes with half-lives greater than 20 years. Without taking into consideration the TMU, the TRU alpha activity concentration for a payload container is determined by dividing the TRU alpha activity of the waste by the weight of the waste. The weight of the waste is the weight of the material placed into the payload container (i.e., the net weight of the container). The weight of the waste is typically determined by subtracting the tare weight of the payload container (including the weight of the rigid liner and any shielding external from the waste, if applicable) from the gross weight of the payload container.	WIPP CH-TRU WAC	900 nCi/g (Based on total alpha analysis of KE NLOP Comp) (Safety Basin KE NLOP composition will give 3X higher value.)
	Plutonium-239 equivalent curie (PE-Ci) is limited for waste containers and packaging configurations • 55-gallon drum in good condition, direct load of all approved waste forms is limited to $\leq$80 ^{239}Pu PE-Ci. • 55-gallon drum in good condition, direct load of solidified/vitrified waste forms is limited to $\leq$1,800 ^{239}Pu PE-Ci. • 55-gallon drum in good condition, direct load of all approved waste forms is limited to $\leq$80 ^{239}Pu PE-Ci. Other waste containers and packaging configurations have other limits. Refer to WIPP CH-TRU WAC.	WIPP CH-TRU WAC	Information related to this item will be provided in 2/2/04 report.
Radiation Dose Equivalent Rate	Waste packages shall not exceed 1 milliSievert per hour (100 millirem per hour) at 30 centimeters (1 foot) from the waste package.	HNF-EP-0063	Information related to this item will be provided in 2/2/04 report.
	Waste packages shall not exceed 2 milliSieverts per hour (200 millirem per hour) at any point on the surface of the package.	HNF-EP-0063	150 mrem/h (Based on modeling.)

Table 5.5 (Contd)

Constraint			Value for TBD alternative
Gas-Generation Properties			
Hydrogen Generation	For any package containing water and/or organic substances that could radiolytically generate combustible gases, a determination must be made by tests and measurements or by analysis of a representative package such that the following criterion is met over a period of time that is twice the expected shipment time: The hydrogen generated must be limited to a molar quantity that would be no more than 5 percent by volume of the innermost layer of confinement (or equivalent limits for other inflammable gases) if present at standard temperature and pressure (STP) (i.e., no more than 0.063 gram-moles/cubic foot at 14.7 pounds per square inch absolute and 32°F). Compliance with this requirement can be achieved by assuring that decay heat limits for each payload container are not exceeded. Per discussions with WIPP personnel during their visit to Hanford on December 16, 2004, the appropriate decay heat limits are as follows: Grout – 0.8800 watt/package Dewatered Sludge – 0.2708 watt/package Nochar – 0.1035 watt/package It should be noted that decay heat limits are dependent on the properties of the waste-form and packaging configuration; the above values are based on treated waste that is packaged in slip-lid cans that are placed within filtered bags in a SPO. These values will bound the decay heat limits for each of the three waste-form options (the other packaging configurations considered in this study—direct loading into a drum, SPO or S200-B Pipe Overpack—would allow for higher heat limits)	TRAMPAC	0.012 W/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004][(a)]) [Appendix E discusses hydrogen generation from chemical reactions.]
(a) Schmidt and Baker. "Updated Design and Safety Basis Values for Physical Properties, Radionuclides, and Chemical Composition of Sludge in the KE Basin North Loadout Pit," PNNL letter report 46497-RPT02 (January 12, 2004), transmitted to WW Rutherford (FH) and JP Slaughter (NHC) by K. L. Silvers (PNNL) on January 12, 2004, via transmittal letter 46497-L03.			

Table 5.5 (Contd)

Constraint			**Value for TBD alternative**
	Gas-Generation Properties		
VOCs	TRU wastes to be transported in the TRUPACT-II are restricted so that no flammable mixtures can occur in any layer of confinement during shipment. While the predominant flammable gas of concern is hydrogen, the presence of methane and flammable VOCs is also limited along with hydrogen to ensure the absence of flammable (gas/VOC) mixtures in TRU waste payloads. Only payload containers (analytical category or test category) that meet the flammable (gas/VOC) limits based on the determinations for compliance with the flammable (gas/VOC) limits are eligible for shipment in the TRUPACT-II. Under the analytical category, a conservative analysis is used to impose decay heat limits on individual payload containers to ensure that flammable (gas/VOC) limits are met. Specifically, flammable VOCs are restricted to less than or equal to 500 parts per million (ppm) in the payload container headspace (to ensure that their contribution to flammability is negligible)	TRAMPAC	Information related to this item will be provided in 3/31/04 report.
Pressure	The gases generated in the payload and released into the ICV cavity shall be controlled to maintain the pressure within the TRUPACT-II ICV cavity below the acceptable design pressure of 50 pounds per square inch gauge (psig). All payloads authorized for transport in the TRUPACT-II will comply with the design pressure limit for a one-year period.	TRAMPAC	Information related to this item will be provided in 3/31/04 report.

HNF-EP-0063, *Hanford Site Solid Waste Acceptance Criteria*, Rev. 9, Fluor Hanford Inc., Richland, Washington, September 2003.

TRAMPAC, *TRUPACT-II Authorized Methods for Payload Control*, Rev. 19c, Washington TRU Solutions, LLC, Carlsbad, New Mexico, April 2003.

WIPP CH-TRU WAC, DOE/WIPP-02-3122, *Contact-Handled Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, Rev 0.1, U. S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico, July 2002.

5.2.2 Evaluation with Respect to Evaluation Criteria

5.2.2.1 Number of Packages Produced

The estimated number of packages for a grouted overpack is slightly more than the grouted drums, based on the waste loading and grout formulation tested in the laboratory. The calculated dose rate is 90 mrem/h at the side of the drum. This is less than the WIPP dose-rate limit and less than the 55-gallon drum grouted directly. The waste loading of 37% results in 16 L of sludge per drum and the production of 396 drums to solidify all the NLOP sludge. If billet cans are used, the number of drums increases to 473 because space is lost and the quantity of sludge per volume of grout was limited by the formulation tested in the laboratory. The dose rate for the billet cans was not calculated directly but would be reduced to approximately 73 mrem/h based on the curie loading.

The number of drums for filling overpacks is based on the waste loading produced in the laboratory that assumed a 50 volume percent increase in water based on the settled sludge weight for sludge-retrieval purposes. It is probable that the waste loading could be increased by using less water to retrieve the sludge and modifying the grout formulation slightly. This form would be recommended over grouting the entire drum.

5.2.2.2 Ease of Rework

A grouted overpack would have about the same difficulty of rework as a grouted drum. Ease of rework would be improved if billet cans were used, but grout removal from the billet cans would still be difficult. It should be noted that if there were a hot spot from improperly mixed grout or unusually high concentration of Cs in the sludge, the inner packages could be unloaded, but rearrangement would not likely provide any benefit.

5.2.2.3 Schedule Viability

The additional number of containers relative to Nochar options increases the risk to the solidification schedule, although the schedule viability is not significantly affected by any of the packaging alternatives.

5.2.2.4 Cost

Grout materials are inexpensive, and the equipment needed to produce the waste would not add significantly to the overall cost. The grout required would be less, but the number of containers required would be higher than for filling grouted drums unless the waste loading was increased. Therefore, the cost is higher for this alternative than for filling 55-gallon drums.

5.3 Polymer Sorbent Solidification Waste Form Within 55-Gallon Drum

5.3.1 Description of Alternative

This waste form consists of a WIPP-certified drum and liner completely filled with sludge and Nochar adsorbent. The formulation used in the table has a much lower waste loading than the one used in the laboratory because of high dose rates. The maximum loading could only be used if additional shielding from a billet can or internal aggregate were used. The laboratory formulation used settled sludge combined with an additional 50-volume percent water, and no additional dewatering steps. The actual batch would have additional water added to create a 23% waste loading that complies with the dose-rates requirements. The sludge and additives would be added directly to the container, mixed, and allowed to solidify.

A comparison of this alternative with the constraints presented in Section 2.0 is provided in Table 5.6. As the table shows, this alternative complies with all of the constraints for which information is currently available. The sludge concentration in the waste container could be increased to match the laboratory formulation by adding aggregate to the Nochar mixture to increase the density or utilize a thickwalled billet canister.

5.3.2 Evaluation with Respect to Evaluation Criteria

5.3.2.1 Number of Packages Produced

The waste loading per 55-gallon drum is limited by dose rate. The estimated number of packages for a polymer sorbent waste form in a 55-gallon drum is much higher than for a 55-gallon grouted drum since the lower density of the Nochar provides less shielding and so can accommodate less sludge while achieving the specified surface dose rate. The number of packages is estimated to be 630 drums with a dose rate less than 160 mrem/h.

5.3.2.2 Ease of Rework

A polymer sorbent waste form could be reworked much more easily than a grouted waste form if the material required retrieval from the primary container.

5.3.2.3 Schedule Viability

The additional number of containers over the overpack option increases the risk to the solidification schedule, although the schedule viability is not significantly affected by any of the packaging alternatives except the S200-B.

5.3.2.4 Cost

The Polymer waste form increases cost because of the additional number of containers.

Table 5.6. Comparison of Polymer Sorbent Solidified Waste Form Within 55-Gallon Drum with Treated-Waste Constraints (5 vol% settled-sludge loading)

Constraint			Value for TBD alternative
Container/Packaging Properties			
Container Types	Only the following payload containers are authorized for shipment in the TRUPACT-II (see Appendix 2.1 of the TRAMPAC document): • 55-Gallon Drum • 100-Gallon Drum • Standard Waste Box (SWB) • Ten-Drum Overpack (TDOP).	TRAMPAC	55-gallon drum with rigid liner and liner lid.
Container Weights	Each payload container and payload assembly shall comply with the following weight limits: Container Weights • 547 pounds per SPO with 12-inch diameter pipe component • 547 pounds per S200 pipe overpack • 1,000 pounds per 55-gallon drum	TRAMPAC	470 lb (includes 77 lbs for drum and liner)
Sealed Containers	Sealed containers that are greater than 4 L (nominal) are prohibited except for Waste Material Type II.2 packaged in a metal container; Waste Material Type II.2 in metal cans does not generate any flammable gas. For this evaluation, no sealed containers will be allowed.	TRAMPAC	No sealed packages. WIPP-compliant filters will be used on drum and liner.
Filter Vents	Vents or other mechanisms to prevent pressurization of containers or generation of flammable or explosive concentrations of gases shall be installed on containers of newly-generated TRU waste at the time the waste is packaged (DOE M 435.1-1, Chapter III, L.1.b.).	HNF-EP-0063	
	Each payload container to be transported in the TRUPACT-II, including all payload containers that are overpacked in other payload containers, shall have one or more filter vents that meet the TRAMPAC specifications. Plastic bags used as confinement layers shall meet the specifications and usage requirements of the TRAMPAC.	TRAMPAC	

Table 5.6 (Contd)

Constraint			Value for TBD alternative
Physical Properties			
Liquid Waste	Liquid waste is prohibited in the payload containers, except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 percent (volume) of the payload container.	TRAMPAC	Observations and measurements performed during the bench-scale waste-form testing (Appendix F) demonstrated that no free liquids were released from waste form.
	Liquid waste is prohibited at WIPP. Waste shall contain as little residual liquid as is reasonably achievable by pouring, pumping, and/or aspirating. Internal containers shall also contain no more than 2.5 cm (1 in.) in the bottom of the internal containers. The total residual liquid in any payload container shall not exceed 1 percent by volume of that payload container. If visual examination methods are used in lieu of radiography, then the detection of any liquids in non-transparent internal containers will be addressed by using the total volume of the internal container when determining the total volume of liquids within the payload container.	WIPP CH-TRU WAC	
Chemical Properties			
Pyrophoric Materials	Pyrophoric radioactive materials shall be present only in small residual amounts (<1 percent [weight]) in payload containers. Radioactive pyrophorics in concentrations greater than 1 percent by weight and all nonradioactive pyrophorics shall be reacted (or oxidized) and/or otherwise rendered nonreactive before placement in the payload container.	TRAMPAC	Initial tests indicate settled sludge contains << 1% U metal (Appendix E).
Radiological/Nuclear Properties			
Decay Heat	If heat generation from radiological decay in the waste package exceeds 3.5 watts per cubic meter (0.1 watt per cubic foot), the package must be evaluated to ensure that the heat does not affect the integrity of the container or surrounding containers in storage. This evaluation must be provided to and approved by the WMP acceptance organization.	HNF-EP-0063	0.0068 W/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004])
Fissile Content	The fissile and fissionable-material content of a package is limited, dependent upon the container and its contents. For 55-gallon or larger steel drums where fissile material is contained in 20% or more of the container volume, the fissionable-material content is limited to 177 fissile gram equivalents (FGE). For 55-gallon or larger steel drums where fissile material is contained in less than 20% of the container volume, the fissionable-material content is limited to 100 FGEs. Limits for other containers are provided in Appendix B of HNF-EP-0063.	HNF-EP-0063	2.3 g FGE/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004])

Table 5.6 (Contd)

Constraint			Value for TBD alternative
Radiological/Nuclear Properties			
Fissile Content	A payload container shall be acceptable for transport only if the ^{239}Pu fissile gram equivalent (FGE) plus two times the measurement error (i.e., two standard deviations) is less than or equal to 200 grams for a 55-gallon drum, a SPO, and an S200 pipe overpack. Note: If a payload container will be overpacked, FGE limits apply only to the outermost payload container of the overpacked configuration.	TRAMPAC	2.3 g FGE/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004])
Curie Content	Up to 35 DE-Ci per container are acceptable at the CWC as a routine shipment. Quantities up to 150 DE-Ci per container can be accepted, but must be evaluated to ensure compliance with facility inventory limits (HNF-SD-WM-ISB-007).	HNF-EP-0063	Information related to this item will be provided in 2/2/04 report.
	TRU waste payload containers shall contain more than 100 nCi/g of alpha-emitting TRU isotopes with half-lives greater than 20 years. Without taking into consideration the TMU, the TRU alpha activity concentration for a payload container is determined by dividing the TRU alpha activity of the waste by the weight of the waste. The weight of the waste is the weight of the material placed into the payload container (i.e., the net weight of the container). The weight of the waste is typically determined by subtracting the tare weight of the payload container (including the weight of the rigid liner and any shielding external from the waste, if applicable) from the gross weight of the payload container.	WIPP CH-TRU WAC	230 nCi/g (Based on total alpha analysis of KE NLOP Comp) (Safety Basin KE NLOP composition will give 3X higher value.)
	Plutonium-239 equivalent curie (PE-Ci) is limited for waste containers and packaging configurations • 55-gallon drum in good condition, direct load of all approved waste forms is limited to $\leq$80 ^{239}Pu PE-Ci. • 55-gallon drum in good condition, direct load of solidified/vitrified waste forms is limited to $\leq$1,800 ^{239}Pu PE-Ci. • 55-gallon drum in good condition, direct load of all approved waste forms is limited to $\leq$80 ^{239}Pu PE-Ci. Other waste containers and packaging configurations have other limits. Refer to WIPP CH-TRU WAC.	WIPP CH-TRU WAC	Information related to this item will be provided in 2/2/04 report.
Radiation Dose Equivalent Rate	Waste packages shall not exceed 1 milliSievert per hour (100 millirem per hour) at 30 centimeters (1 foot) from the waste package.	HNF-EP-0063	Information related to this item will be provided in 2/2/04 report.
	Waste packages shall not exceed 2 milliSieverts per hour (200 millirem per hour) at any point on thc surface of the package.	HNF-EP-0063	190 mrem/h (Based on modeling).

Table 5.6 (Contd)

Constraint			Value for TBD alternative
Gas-Generation Properties			
Hydrogen Generation	For any package containing water and/or organic substances that could radiolytically generate combustible gases, determination must be made by tests and measurements or by analysis of a representative package such that the following criterion is met over a period of time that is twice the expected shipment time: The hydrogen generated must be limited to a molar quantity that would be no more than 5 percent by volume of the innermost layer of confinement (or equivalent limits for other inflammable gases) if present at standard temperature and pressure (STP) (i.e., no more than 0.063 gram-moles/cubic foot at 14.7 pounds per square inch absolute and 32°F). Compliance with this requirement can be achieved by assuring that decay heat limits for each payload container are not exceeded. Per discussions with WIPP personnel during their visit to Hanford on December 16, 2004, the appropriate decay heat limits are as follows: Grout – 0.8800 watt/package Dewatered Sludge – 0.2708 watt/package Nochar – 0.1035 watt/package It should be noted that decay heat limits are dependent on the properties of the waste-form and packaging configuration; the above values are based on treated waste that is packaged in slip-lid cans that are placed within filtered bags in a SPO. These values will bound the decay heat limits for each of the three waste-form options (the other packaging configurations considered in this study—direct loading into a drum, SPO, or S200-B Pipe Overpack—would allow for higher heat limits)	TRAMPAC	0.0068 W/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004]) (Appendix E discusses hydrogen generation from chemical reactions.)

Table 5.6 (Contd)

Constraint			Value for TBD alternative
Gas-Generation Properties			
VOCs	TRU wastes to be transported in the TRUPACT-II are restricted so that no flammable mixtures can occur in any layer of confinement during shipment. While the predominant flammable gas of concern is hydrogen, the presence of methane and flammable VOCs is also limited along with hydrogen to ensure the absence of flammable (gas/VOC) mixtures in TRU waste payloads. Only payload containers (analytical category or test category) that meet the flammable (gas/VOC) limits based on the determinations for compliance with the flammable (gas/VOC) limits are eligible for shipment in the TRUPACT-II. Under the analytical category, a conservative analysis is used to impose decay heat limits on individual payload containers to ensure that flammable (gas/VOC) limits are met. Specifically, flammable VOCs are restricted to less than or equal to 500 parts per million (ppm) in the payload container headspace (to ensure that their contribution to flammability is negligible).	TRAMPAC	Information related to this item will be provided in 3/31/04 report.
Pressure	The gases generated in the payload and released into the ICV cavity shall be controlled to maintain the pressure within the TRUPACT-II ICV cavity below the acceptable design pressure of 50 pounds per square inch gauge (psig). All payloads authorized for transport in the TRUPACT-II will comply with the design pressure limit for a one-year period.	TRAMPAC	Information related to this item will be provided in 3/31/04 report.

HNF-EP-0063, *Hanford Site Solid Waste Acceptance Criteria*, Rev. 9, Fluor Hanford Inc., Richland, Washington, September 2003.

TRAMPAC, *TRUPACT-II Authorized Methods for Payload Control*, Rev. 19c, Washington TRU Solutions, LLC, Carlsbad, New Mexico, April 2003.

WIPP CH-TRU WAC, DOE/WIPP-02-3122, *Contact-Handled Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, Rev 0.1, U. S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico, July 2002.

5.4 Polymer Sorbent Solidification Waste Form in Standard Pipe Overpack Packaged in 55-Gallon Drum

5.4.1 Description of Alternative

This waste form consists of a WIPP-certified overpack completely filled with Nochar adsorbent, or inner billet containers would be filled, bagged, and placed within the overpack container and the accompanying drum. The billet cans would be sized to allow two in an SPO. The formulation used was the same as the one demonstrated in the laboratory, consisting of Nochar, water, and settled sludge. The settled sludge was assumed to be combined with additional water to maintain the dose-rate criteria.. The sludge and additives would be added directly to the overpack or billet cans, mixed, and allowed to solidify.

A comparison of this alternative with the constraints presented in Section 2.0 is provided in Table 5.7. As the table shows, this alternative complies with all of the constraints for which information is currently available.

5.4.2 Evaluation with Respect to Evaluation Criteria

5.4.2.1 Number of Packages Produced

The number of packages is limited by dose rate for the SPOs in a 55-gallon drum, based on a waste loading of 29%, which is lower than achieved in the laboratory. Additional water would be used to dilute the mixture from the minimal amount assumed for retrieval. The estimated number of packages for a polymer sorbent waste form in an overpack is 630 with a waste loading of 29% and a dose rate of 160 mrem/h. This alternative produces a higher lowest number of waste packages, except for Nochar in a 55-gallon drum as discussed in Section 5.5..

Using two billet cans inside the overpack would likely decrease the number of drums if the billet cans provide some significant shielding. In this analysis, the shielding affect of the billet cans was not included.

An increase in waste loading may be possible after production is underway and dose-rate projections are verified, which would reduce the number of drums produced.

5.4.2.2 Ease of Rework

A polymer sorbent waste form could be reworked much more easily than a grouted waste form if the material required retrieval from the primary container.

5.4.2.3 Schedule Viability

With the exception of dewatered sludge packaged in S200-B SPOs, this option produces the fewest containers and is the simplest process to implement. Dose-rate variations from inadequate mixing are the largest process risk that could affect schedule.

5.4.2.4 Cost

Unless the waste loading could be increased, the cost for this alternative is greater than for grouted containers because of the additional number of drums produced. Polymer materials are also more expensive than grout additives per container, even though less material is used. Material costs are not significant in the overall cost.

Table 5.7. Comparison of Polymer Sorbent Solidified Waste Form Within Pipe Overpack Container Packaged Within 55-Gallon Drum with Treated-Waste Constraints (23 vol% settled-sludge loading)

Constraint			Value for TBD alternative
Container/Packaging Properties			
Container Types	Only the following payload containers are authorized for shipment in the TRUPACT-II (see Appendix 2.1 of the TRAMPAC document): • 55-Gallon Drum • 100-Gallon Drum • Standard Waste Box (SWB) • Ten-Drum Overpack (TDOP).	TRAMPAC	SPO within a 55-gallon drum.
	Only the following containers are authorized for disposal as CH-TRU at WIPP: • 55-Gallon Drums (either direct loaded or containing a pipe component) • SWBs, either direct loaded, or containing up to four direct loaded 55-gallon drums, or containing one bin. • TDOPs, either containing up to ten direct loaded 55-gallon drums, six 85-gallon drum overpacks, or one SWB.	WIPP CH-TRU WAC	
Container Weights	Each payload container and payload assembly shall comply with the following weight limits: <u>Container Weights</u> • 547 pounds per SPO with 12-in.-diameter pipe component • 547 pounds per S200 pipe overpack • 1,000 pounds per 55-gallon drum.	TRAMPAC	420 lb (includes 332 lb for pipe component and drum)
Sealed Containers	Sealed containers that are greater than 4 L (nominal) are prohibited except for Waste Material Type II.2 packaged in a metal container; Waste Material Type II.2 in metal cans does not generate any flammable gas. For this evaluation, no sealed containers will be allowed.	TRAMPAC	No sealed packages. WIPP-compliant filters will be used on drum and pipe component (and bags if billet cans are used).
Filter Vents	Vents or other mechanisms to prevent pressurization of containers or generation of flammable or explosive concentrations of gases shall be installed on containers of newly-generated TRU waste at the time the waste is packaged (DOE M 435.1-1, Chapter III, L.1.b.).	HNF-EP-0063	
	Each payload container to be transported in the TRUPACT-II, including all payload containers that are overpacked in other payload containers, shall have one or more filter vents that meet the TRAMPAC specifications. Plastic bags used as confinement layers shall meet the specifications and usage requirements of the TRAMPAC.	TRAMPAC	

Table 5.7 (Contd)

Constraint			Value for TBD alternative
Physical Properties			
Liquid Waste	Liquid waste is prohibited in the payload containers, except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 percent (volume) of the payload container.	TRAMPAC	Observations and measurements performed during the bench-scale waste-form testing (Appendix F) demonstrated that no free liquids were released from waste form.
	Liquid waste is prohibited at WIPP. Waste shall contain as little residual liquid as is reasonably achievable by pouring, pumping, and/or aspirating. Internal containers shall also contain no more than 1 inch or 2.5 cm in the bottom of the internal containers. The total residual liquid in any payload container shall not exceed 1 percent by volume of that payload container. If visual examination methods are used in lieu of radiography, then the detection of any liquids in non-transparent internal containers will be addressed by using the total volume of the internal container when determining the total volume of liquids within the payload container.	WIPP CH-TRU WAC	
Chemical Properties			
Pyrophoric Materials	Pyrophoric radioactive materials shall be present only in small residual amounts (<1 percent [weight]) in payload containers. Radioactive pyrophorics in concentrations greater than 1 percent by weight and all nonradioactive pyrophorics shall be reacted (or oxidized) and/or otherwise rendered nonreactive before placement in the payload container.	TRAMPAC	Initial tests indicate that settled sludge contains <<1% U metal (Appendix E).
	Pyrophoric radioactive materials shall be present only in small residual amounts (<1 percent by weight) in payload containers and shall be generally dispersed in the waste.	WIPP CH-TRU WAC	
Radiological/Nuclear Properties			
Decay Heat	If heat generation from radiological decay in the waste package exceeds 3.5 watts per cubic meter (0.1 watt per cubic foot), the package must be evaluated to ensure that the heat does not affect the integrity of the container or surrounding containers in storage. This evaluation must be provided to and approved by the WMP acceptance organization.	HNF-EP-0063	0.0076 W/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004])
Fissile Content	The fissile and fissionable-material content of a package is limited, dependent upon the container and its contents. For 55-gallon or larger steel drums where fissile material is contained in 20% or more of the container volume, the fissionable-material content is limited to 177 fissile gram equivalents (FGEs). For 55-gallon or larger steel drums where fissile material is contained in less than 20% of the container volume, the fissionable-material content is limited to 100 FGEs. Limits for other containers are provided in Appendix B of HNF-EP-0063.	HNF-EP-0063	2.6 g FGE/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004])

Table 5.7 (Contd)

Constraint			Value for TBD alternative
Radiological/Nuclear Properties			
	A payload container shall be acceptable for transport only if the ^{239}Pu fissile gram equivalent (FGE) plus two times the measurement error (i.e., two standard deviations) is less than or equal to 200 grams for a 55-gallon drum, a SPO, and an S200 pipe overpack. Note: If a payload container will be overpacked, FGE limits apply only to the outermost payload container of the overpacked configuration.	TRAMPAC	
Curie Content	Up to 35 DE-Ci per container are acceptable at the CWC as a routine shipment. Quantities up to 150 DE-Ci per container can be accepted, but must be evaluated to ensure compliance with facility inventory limits (HNF-SD-WM-ISB-007).	HNF-EP-0063	Information related to this item will be provided in 2/2/04 report.
	TRU waste payload containers shall contain more than 100 nCi/g of alpha-emitting TRU isotopes with half-lives greater than 20 years. Without taking into consideration the TMU, the TRU alpha activity concentration for a payload container is determined by dividing the TRU alpha activity of the waste by the weight of the waste. The weight of the waste is the weight of the material placed into the payload container (i.e., the net weight of the container). The weight of the waste is typically determined by subtracting the tare weight of the payload container (including the weight of the rigid liner and any shielding external from the waste, if applicable) from the gross weight of the payload container.	WIPP CH-TRU WAC	1,100 nCi/g (Based on total alpha analysis of KE NLOP Comp) (Safety Basin KE NLOP composition will give 3X higher value.)
	Plutonium-239 equivalent curie (PE-Ci) is limited for waste containers and packaging configurations • 55-gallon drum in good condition, direct load of all approved waste forms is limited to $\leq$80 ^{239}Pu PE-Ci. • 55-gallon drum in good condition, direct load of solidified/vitrified waste forms is limited to $\leq$1,800 ^{239}Pu PE-Ci. • 55-gallon drum in good condition, direct load of all approved waste forms is limited to $\leq$80 ^{239}Pu PE-Ci. Other waste containers and packaging configurations have other limits. Refer to WIPP CH-TRU WAC.	WIPP CH-TRU WAC	Information related to this item will be provided in 2/2/04 report.
Radiation Dose Equivalent Rate	Waste packages shall not exceed 1 milliSievert per hour (100 millirem per hour) at 30 centimeters (1 foot) from the waste package.	HNF-EP-0063	Information related to this item will be provided in 2/2/04 report.
	Waste packages shall not exceed 2 milliSieverts per hour (200 millirem per hour) at any point on the surface of the package.	HNF-EP-0063	160 mrem/h (Based on modeling.)

Table 5.7 (Contd)

Constraint			Value for TBD alternative
Gas-Generation Properties			
Hydrogen Generation	For any package containing water and/or organic substances that could radiolytically generate combustible gases, a determination must be made by tests and measurements or by analysis of a representative package such that the following criterion is met over a period of time that is twice the expected shipment time: The hydrogen generated must be limited to a molar quantity that would be no more than 5 percent by volume of the innermost layer of confinement (or equivalent limits for other inflammable gases) if present at standard temperature and pressure (STP) (i.e., no more than 0.063 gram-moles/cubic foot at 14.7 pounds per square inch absolute and 32°F). Compliance with this requirement can be achieved by assuring that decay heat limits for each payload container are not exceeded. Per discussions with WIPP personnel during their visit to Hanford on December 16, 2004, the appropriate decay heat limits are as follows: Grout – 0.8800 watt/package Dewatered Sludge – 0.2708 watt/package Nochar – 0.1035 watt/package It should be noted that decay heat limits are dependent on the properties of the waste-form and packaging configuration; the above values are based on treated waste that is packaged in slip-lid cans that are placed within filtered bags in a SPO. These values will bound the decay heat limits for each of the three waste-form options (the other packaging configurations considered in this study—direct loading into a drum, SPO, or S200-B Pipe Overpack—would allow for higher heat limits)	TRAMPAC	0.0076 W/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004]) (Appendix E discusses hydrogen generation from chemical reactions.)

Table 5.7 (Contd)

Constraint			**Value for TBD alternative**
Gas-Generation Properties			
VOCs	TRU wastes to be transported in the TRUPACT-II are restricted so that no flammable mixtures can occur in any layer of confinement during shipment. While the predominant flammable gas of concern is hydrogen, the presence of methane and flammable VOCs is also limited along with hydrogen to ensure the absence of flammable (gas/VOC) mixtures in TRU waste payloads. Only payload containers (analytical category or test category) that meet the flammable (gas/VOC) limits based on the determinations for compliance with the flammable (gas/VOC) limits are eligible for shipment in the TRUPACT-II. Under the analytical category, a conservative analysis is used to impose decay heat limits on individual payload containers to ensure that flammable (gas/VOC) limits are met. Specifically, flammable VOCs are restricted to less than or equal to 500 parts per million (ppm) in the payload container headspace (to ensure that their contribution to flammability is negligible)	TRAMPAC	Information related to this item will be provided in 3/31/04 report.
Pressure	The gases generated in the payload and released into the ICV cavity shall be controlled to maintain the pressure within the TRUPACT-II ICV cavity below the acceptable design pressure of 50 pounds per square inch gauge (psig). All payloads authorized for transport in the TRUPACT-II will comply with the design pressure limit for a 1-year period.	TRAMPAC	Information related to this item will be provided in 3/31/04 report.

HNF-EP-0063, *Hanford Site Solid Waste Acceptance Criteria*, Rev. 9, Fluor Hanford Inc., Richland, Washington, September 2003.

TRAMPAC, *TRUPACT-II Authorized Methods for Payload Control*, Rev. 19c, Washington TRU Solutions, LLC, Carlsbad, New Mexico, April 2003.

WIPP CH-TRU WAC, DOE/WIPP-02-3122, *Contact-Handled Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, Rev 0.1, U. S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico, July 2002.

5.5 Dewatered Sludge in S200B shielded Pipe Overpack Container Packaged Within 55-Gallon Drum

This waste form consists of a WIPP-certified drum, liner, and S200-B SPO. The S200-B package would be completely filled with dewatered sludge with some small amount of Nochar used as void space filler. The concentration formulated for the dewatered sludge was based on laboratory demonstrations that decreased the total volume by a factor of 2 for a unit volume of settled sludge.

The dewatering would take place in the S200-B container that would be filled to approximately 85% of the maximum volume. The total weight of the dewatered sludge per container would be near the payload weight allowable for the S200-B package (50 lbs).

A comparison of this alternative with the constraints presented in Section 2.0 is provided in Table 5.8. As the table shows, this alternative complies with all of the constraints for which information is currently available.

5.5.1 Evaluation with Respect to Evaluation Criteria

5.5.1.1 Number of Packages Produced

The estimated number of packages for dewatered sludge in a S200-B package is limited by the volume of the container and the dewatering ability of the process. Assuming the container can be filled to ~80% of its maximum volume of about 14 L, approximately 22 L of dewatered sludge could be placed inside the S200-B. Based on this volume, 286 WIPP packages would be produced. No other WIPP limits are approached except for the weight limit on the S200-B package, which could cause a 10% increase in the number of drums to meet the weight limits. The small amount of material in the container and the significant internal shielding allows the dose rate to be less than 55 mrem/h. Polymer absorbent could be added to the top head space to ensure that no free water exists, but no increase in the amount of sludge per container could be made.

5.5.1.2 Ease of Rework

Dewatered sludge would be the relatively easy to rework because there are no hard immobile or organic chemicals in the package; however, the material would be dispersible, and the contact dose rate of the material would be very high and would probably require a shielded location.

5.5.1.3 Schedule Viability

The dewatering process is not thoroughly developed, which provides the greatest risk to the schedule viability. Also, it is unlikely that the S200-B SPOs could be procured on a schedule that is consistent with the project schedule, particularly the requirement that Fluor receive the first 30 packages by March 1, 2003.

5.5.1.4 Cost

The dewatering process in an S200-B would be expensive since the process is more difficult to implement than the other processes, and the waste package is expected to cost more per package, although the number of waste packages is lower than the other options. Waste package cost alone would be less expensive then the other options because there would be significantly fewer drums.

Table 5.8. Comparison of Dewatered Sludge in S200-B Shielded Pipe Overpack Container Packaged Within 55-Gallon Drum with Treated-Waste Constraints (200 vol% settled sludge loading)

Constraint			Value for TBD alternative
Container/Packaging Properties			
Container Types	Only the following payload containers are authorized for shipment in the TRUPACT-II (see Appendix 2.1 of the TRAMPAC document): • 55-Gallon Drum • 100-Gallon Drum • Standard Waste Box (SWB) • Ten-Drum Overpack (TDOP).	TRAMPAC	S200-B shielded pipe overpack container within 55-gallon drum.
	Only the following containers are authorized for disposal as CH-TRU at WIPP: • 55-Gallon Drums (either direct loaded or containing a pipe component) • SWBs, either direct loaded, or containing up to four direct loaded 55-gallon drums, or containing one bin. • TDOPs, either containing up to ten direct loaded 55-gallon drums, six 85-gallon drum overpacks, or one SWB.	WIPP CH-TRU WAC	
Container Weights	Each payload container and payload assembly shall comply with the following weight limits: <u>Container Weights</u> • 547 pounds per SPO with 12-inch diameter pipe component • 547 pounds per S200 pipe overpack • 1,000 pounds per 55-gallon drum.	TRAMPAC	530 lb (includes 497 lb for pipe components, shielding, dunnage, and drum)
Sealed Containers	Sealed containers that are greater than 4 L (nominal) are prohibited except for Waste Material Type II.2 packaged in a metal container; Waste Material Type II.2 in metal cans does not generate any flammable gas. For this evaluation, no sealed containers will be allowed.	TRAMPAC	No sealed packages. WIPP-compliant filters will be used on drum and shield assembly.
Filter Vents	Vents or other mechanisms to prevent pressurization of containers or generation of flammable or explosive concentrations of gases shall be installed on containers of newly generated TRU waste at the time the waste is packaged (DOE M 435.1-1, Chapter III, L.1.b.).	HNF-EP-0063	
	Each payload container to be transported in the TRUPACT-II, including all payload containers that are overpacked in other payload containers, shall have one or more filter vents that meet the TRAMPAC specifications. Plastic bags used as confinement layers shall meet the specifications and usage requirements of the TRAMPAC.	TRAMPAC	

Table 5.8 (Contd)

Constraint			Value for TBD alternative
Physical Properties			
Liquid Waste	Liquid waste is prohibited in the payload containers, except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 percent (volume) of the payload container.	TRAMPAC	Observations and measurements performed during the bench-scale waste-form testing (Appendix F) demonstrated that no free liquids were released from waste form.
	Liquid waste is prohibited at WIPP. Waste shall contain as little residual liquid as is reasonably achievable by pouring, pumping, and/or aspirating. Internal containers shall also contain no more than 2.5 cm (1 in.) in the bottom of the internal containers. The total residual liquid in any payload container shall not exceed 1 percent by volume of that payload container. If visual examination methods are used in lieu of radiography, then the detection of any liquids in non-transparent internal containers will be addressed by using the total volume of the internal container when determining the total volume of liquids within the payload container.	WIPP CH-TRU WAC	
Chemical Properties			
Pyrophoric Materials	Pyrophoric radioactive materials shall be present only in small residual amounts (<1 percent [weight]) in payload containers. Radioactive pyrophorics in concentrations greater than 1 percent by weight and all nonradioactive pyrophorics shall be reacted (or oxidized) and/or otherwise rendered nonreactive before placement in the payload container.	TRAMPAC	Initial tests indicate that settled sludge contains <<1% U metal (Appendix E).
	Pyrophoric radioactive materials shall be present only in small residual amounts (<1 percent by weight) in payload containers and shall be generally dispersed in the waste.	WIPP CH-TRU WAC	
Radiological/Nuclear Properties			
Decay Heat	If heat generation from radiological decay in the waste package exceeds 3.5 watts per cubic meter (0.1 watt per cubic foot), the package must be evaluated to ensure that the heat does not affect the integrity of the container or surrounding containers in storage. This evaluation must be provided to and approved by the WMP acceptance organization.	HNF-EP-0063	0.017 W/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004])
Fissile Content	The fissile and fissionable-material content of a package is limited, dependent upon the container and its contents. For 55-gallon or larger steel drums where fissile material is contained in 20% or more of the container volume, the fissionable-material content is limited to 177 fissile gram equivalents (FGE). For 55-gallon or larger steel drums where fissile material is contained in less than 20% of the container volume, the fissionable-material content is limited to 100 FGEs. Limits for other containers are provided in Appendix B of HNF-EP-0063.	HNF-EP-0063	5.7 g FGE/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004])

Table 5.8 (Contd)

Constraint			Value for TBD alternative
Radiological/Nuclear Properties			
Fissile Content	A payload container shall be acceptable for transport only if the ^{239}Pu fissile gram equivalent (FGE) plus two times the measurement error (i.e., two standard deviations) is less than or equal to 200 grams for a 55-gallon drum, a SPO, and an S200 pipe overpack. Note: If a payload container will be overpacked, FGE limits apply only to the outermost payload container of the overpacked configuration.	TRAMPAC	5.7 g FGE/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004])
Curie Content	Up to 35 DE-Ci per container are acceptable at the CWC as a routine shipment. Quantities up to 150 DE-Ci per container can be accepted, but must be evaluated to ensure compliance with facility inventory limits (HNF-SD-WM-ISB-007).	HNF-EP-0063	Information related to this item will be provided in 2/2/04 report.
	S200 pipe overpack payloads shall meet the package specific curie limits in the TRAMPAC (see Appendices 2.3 and 2.4, respectively).	TRAMPAC	Information related to this item will be provided in 2/2/04 report.
	TRU waste payload containers shall contain more than 100 nCi/g of alpha-emitting TRU isotopes with half-lives greater than 20 years. Without taking into consideration the TMU, the TRU alpha activity concentration for a payload container is determined by dividing the TRU alpha activity of the waste by the weight of the waste. The weight of the waste is the weight of the material placed into the payload container (i.e., the net weight of the container). The weight of the waste is typically determined by subtracting the tare weight of the payload container (including the weight of the rigid liner and any shielding external from the waste, if applicable) from the gross weight of the payload container.	WIPP CH-TRU WAC	6,200 nCi/g (Based on total alpha analysis of KE NLOP Comp) (Safety Basin KE NLOP composition will give 3X higher value.)
	Plutonium-239 equivalent curie (PE-Ci) is limited for waste containers and packaging configurations • 55-gallon drum in good condition, direct load of all approved waste forms is limited to $\leq$80 ^{239}Pu PE-Ci. • 55-gallon drum in good condition, direct load of solidified/vitrified waste forms is limited to $\leq$1,800 ^{239}Pu PE-Ci. • 55-gallon drum in good condition, direct load of all approved waste forms is limited to $\leq$80 ^{239}Pu PE-Ci. Other waste containers and packaging configurations have other limits. Refer to WIPP CH-TRU WAC.	WIPP CH-TRU WAC	Information related to this item will be provided in 2/2/04 report.

Table 5.8 (Contd)

Constraint			Value for TBD alternative
Radiological/Nuclear Properties			
Radiation Dose Equivalent Rate	Waste packages shall not exceed 1 milliSievert per hour (100 millirem per hour) at 30 cm (1 ft) from the waste package.	HNF-EP-0063	Information related to this item will be provided in 2/2/04 report.
	Waste packages shall not exceed 2 milliSieverts per hour (200 millirem per hour) at any point on the surface of the package.	HNF-EP-0063	55 mrem/h (Based on modeling.)
Gas-Generation Properties			
Hydrogen Generation	For any package containing water and/or organic substances that could radiolytically generate combustible gases, determination must be made by tests and measurements or by analysis of a representative package such that the following criterion is met over a period of time that is twice the expected shipment time: The hydrogen generated must be limited to a molar quantity that would be no more than 5 percent by volume of the innermost layer of confinement (or equivalent limits for other inflammable gases) if present at standard temperature and pressure (STP) (i.e., no more than 0.063 gram-moles/cubic foot at 14.7 pounds per square inch absolute and 32°F). Compliance with this requirement can be achieved by assuring that decay heat limits for each payload container are not exceeded. Per discussions with WIPP personnel during their visit to Hanford on December 16, 2004, the appropriate decay heat limits are as follows: Grout – 0.8800 watt/package Dewatered Sludge – 0.2708 watt/package Nochar – 0.1035 watt/package It should be noted that decay heat limits are dependent on the properties of the waste-form and packaging configuration; the above values are based on treated waste that is packaged in slip-lid cans that are placed within filtered bags in a SPO. These values will bound the decay heat limits for each of the three waste-form options (the other packaging configurations considered in this study—direct loading into a drum, SPO, or S200-B Pipe Overpack—would allow for higher heat limits)	TRAMPAC	0.017 W/drum (Based on KE NLOP Safety Basis Composition [Schmidt and Baker, 2004]) (Appendix E discusses hydrogen generation from chemical reactions.)

Table 5.8 (Contd)

Constraint			Value for TBD alternative
Gas-Generation Properties			
VOCs	TRU wastes to be transported in the TRUPACT-II are restricted so that no flammable mixtures can occur in any layer of confinement during shipment. While the predominant flammable gas of concern is hydrogen, the presence of methane and flammable VOCs is also limited along with hydrogen to ensure the absence of flammable (gas/VOC) mixtures in TRU waste payloads. Only payload containers (analytical category or test category) that meet the flammable (gas/VOC) limits based on the determinations for compliance with the flammable (gas/VOC) limits are eligible for shipment in the TRUPACT-II. Under the analytical category, a conservative analysis is used to impose decay heat limits on individual payload containers to ensure that flammable (gas/VOC) limits are met. Specifically, flammable VOCs are restricted to less than or equal to 500 parts per million (ppm) in the payload container headspace (to ensure that their contribution to flammability is negligible).	TRAMPAC	Information related to this item will be provided in 3/31/04 report.
Pressure	The gases generated in the payload and released into the ICV cavity shall be controlled to maintain the pressure within the TRUPACT-II ICV cavity below the acceptable design pressure of 50 pounds per square inch gauge (psig). All payloads authorized for transport in the TRUPACT-II will comply with the design pressure limit for a 1-year period.	TRAMPAC	Information related to this item will be provided in 3/31/04 report.

HNF-EP-0063, *Hanford Site Solid Waste Acceptance Criteria*, Rev. 9, Fluor Hanford Inc., Richland, Washington, September 2003.

TRAMPAC, *TRUPACT-II Authorized Methods for Payload Control*, Rev. 19c, Washington TRU Solutions, LLC, Carlsbad, New Mexico, April 2003.

WIPP CH-TRU WAC, DOE/WIPP-02-3122, *Contact-Handled Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, Rev 0.1, U. S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico, July 2002.

6.0 Conclusions and Recommendations

6.1 Conclusions

6.1.1 Waste Form

Three waste forms for treated KE NLOP sludge were considered in this study:

- grout
- Nochar
- dewatered sludge.

Based on the results of this study, all three of these waste forms could be used to produce CH-TRU that would meet the constraints identified in Section 3 of this report. However, it would be more difficult to ensure that the free-water restriction would be met with dewatered sludge than with either grout or Nochar.

From a processing standpoint, either of the solidification options (grout or Nochar) would be simpler than dewatering. Also, treating of the sludge with Nochar would be somewhat simpler than using grout because only one additive to the sludge would be required (Nochar) compared to grout (Portland cement and bentonite clay); and compared to grout, Nochar would be able to accommodate a larger range of solidification agent/water/sludge ratios, which would enhance the robustness of the process except for the dose-rate limits.

6.1.2 Waste-Package Configuration

Four waste-package configurations were considered in this study:

- direct loading of the treated waste in 55-gallon drums
- direct loading of the treated waste in SPOs
- loading of the treated waste in billet cans that would be placed in vented plastic bags and then loaded in SPOs
- direct loading of the treated sludge in S200-B SPO.

All four of these waste-package configurations could be used to produce CH-TRU that would meet the constraints identified in Section 3 of this report. However, due to the dose rate associated with the dewatered sludge, the use of the S200-B would be required for this waste form. Conversely, the shielding provided by the S200-B would not be required for grout and Nochar, and the limited volume of this package would drive up the number of packages produced. For grout and Nochar, the use of drums or SPOs (either direct loaded or using billet cans) could be considered.

It should be noted that S200-B SPOs are not frequently used, and the lead-time associated with procurement of these packages would likely prevent the May 1 deadline for production of the first 30 packages to be met.

6.1.3 Number of Waste Packages

For the dewatered sludge loaded into S200-B Shielded Pipe Overpacks, the number of waste packages was driven by the waste package and sludge volumes. For all other options, the requirement that the surface dose rate be $\leq$200 mrem/h drove the estimated number of packages to be produced. All other requirements that are impacted by sludge characteristics, such as the package limitations on FGE and decay heat, will be met if the surface dose-rate limitation is achieved.

It is estimated that the fewest number of packages (approximately 286) would be produced if dewatered sludge were packaged in S200-B Shielded Pipe Overpacks. The next fewest number of packages (approximately 396) would be produced using grout as the waste form and packaging the treated waste in SPOs directly.

6.2 Recommendations

It is recommended that the KE NLOP sludge be treated using Nochar and that the treated waste be packaged in billet cans that would be placed in vented plastic bags and then loaded in SPOs. This recommendation is based on a number of considerations that are summarized below:

- Treatment of the sludge with Nochar would result in a robust process that is not sensitive to variations in processing conditions.
- The use of billet cans would facilitate rework and/or repackaging of the treated sludge by Fluor in the unlikely event that this becomes necessary; the use of Nochar would facilitate rework of the waste form itself.
- The use of billet cans and the low density of the Nochar waste form will facilitate that assay process that Fluor will complete as part of WIPP certification.
- Nochar has already been accepted for use by WIPP (its use is identified in TRUPACT-II Content Code RF-127 ("the waste form is produced by combining the inorganic aqueous liquid/sludge waste material with a polymer-based solidification agent [e.g., Nochar Acid bond, Water Works Crystals, etc.]…").
- The Nochar, SPO, billet cans, and vented plastic bags are commercially available and could be procured in time to support the project schedule.

It should be noted that the above recommendation is not sensitive to the assumptions that are made about the radiochemical composition of the sludge. The estimated numbers of packages that were determined as part of this study were based on data from characterization of the core samples that were received from Fluor to support this study. If other assumptions regarding source term had been used to estimate the numbers of packages to be produced for each option (e.g., use of Safety Basis values), the package count estimates would likely be different. However, the relative numbers of packages for one option compared to another option would not be expected to change substantially.

It should also be noted that implementation of this recommendation will require approval from the Environmental Protection Agency (EPA) for solidification of wet sludge (this issue is being addressed as part of the *Time Critical CERCLA Regulatory Action* that Fluor is preparing for submission to EPA). It is anticipated that resolution of this issue will be reached by March 1, 2004.

Finally, as noted in Section 5, additional information about the characteristics of the treated waste, such as values for DE-Ci and PE-Ci, and information related to VOC releases during gas-generation testing and ICV pressure limits, will be provided in the "initial analytical results package" and "final analytical results package." Per Delegard (2003), these reports will be issued on February 2, 2003, and March 31, 2004, respectively. It is not expected that these additional results will impact the recommendation provided in this report.

7.0 References

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Appendix A

Sample Collection

Appendix A: Sample Collection Sample Collection from the Sludge in the KE Basin North Loadout Pit

RB Baker and JA Serles

A.1 Sampling Objectives

Sampling of the sludge in the KE NLOP was performed consistent with the controlling Test Plan (Delegard 2003). The objective of this sampling campaign was to draw an axial core sample from the sludge in the KE NLOP main pit to recover between 1 and 1.5 L of representative as-settled sludge for disposal process development. The sample was to be taken at the most efficient and accessible position in the main pit area—this position was concluded to be adjacent to the location sampled in the main pit during the 1999 sampling campaign (Baker et al. 1998); this is also the area expected to have one of the deepest accumulations of sludge in the KE NLOP. The sample material was to be delivered to the 325 Building Laboratory by December 24, 2003.

A.2 Acquiring Sludge Core Sample

A.2.1 General Overview

The representative sludge-sample material was drawn using equipment and techniques successfully used in past characterization sampling performed on the KE Basin sludges in 1995 and 1999 (Baker et al. 1998; Baker 1998; Makenas and Baker 1998). As noted in the Sampling and Analysis Plan for the 1999 campaign (Baker et al. 1998), it was expected that there was a minimal difference in sludge composition laterally across the pit and transfer channel because the layers of backwash water and suspended materials would deposit relatively proportionally across the pit; however, it was very likely there was a large difference in sludge composition axially down through the sludge accumulation (e.g., different activities in the basin over the years of operation would result in different material in layers, different settling behavior of the backflushed material [e.g., filter sand, fuel corrosion products] would result in substructure within the layers, and different operations in the pit [e.g., sparging] would influence the bulk layers). These expectations are supported by the overall results from sludge sampling in the pit performed in 1993 (Warner 1994—showing a general consistency laterally across the pit and transfer channel) and 1999 (Pitner 1999—showing a significant difference in material from the top to the floor as indicated by activity of sample bottles).

For the current campaign, a 2-in.-diameter axial (i.e., top surface to floor) core of sludge was taken and shipped in multiple 4-L bottles to the laboratory. These bottles contained varying amounts of sludge solids (all bottles were adjusted after sampling was complete by decanting so when shipped they had 2 L of head space. Six primary sample bottles were required for the core. Combining material from all the bottles provides a sludge sample representative of the average axial material. Because of the way the sampling equipment functions, sequential pairs of primary sample bottles can also, if their solids are analyzed separately, provide insight into the axial layers of material encountered in the core, working down toward the floor.

A.2.2 Sampling Equipment

The sampling equipment used (Figure A1 and A2) is described in detail in the System Design Description (Baker 1998). The application of this equipment was similar to the 1999 sampling campaign (Pitner 1999) with one exception: there was a requirement that for shipping in the PAS-1 Cask, a 2-L head space must be provided in each shipped bottle—this required transferring (decanting) approximately 2 L of carrier water from each full primary sample bottle to another bottle before shipment. Any time the carrier water was decanted, accommodation was made either to not lose significant fine suspended solids (e.g., wait for the fine material to settle from the carrier water), or the decant water bottle was inspected, and if significant solids were observed, the decant bottle was also shipped to the laboratory to be combined with the other solids. The suspended solids are likely to include fuel-rich material in this case because of the source of the NLOP sludge (i.e., basin skimmer system).

A.2.3 Acquiring the Sample

Isolating the Sludge Core. A 2-in.-diameter isolation tube was inserted into the sludge. At the time of sampling, the KE NLOP had a plywood cover at the deck level for Basin operational safety reasons. The isolation tube was placed through the same slot in this plywood as was used in the 1999 campaign (Pitner 1999). (Since the isolation tube from the 1999 campaign had not been removed, a visual reference was provided to ensure that the December 2003 sample was collected from an undisturbed location.) This location is near the middle of the east side of the main pit where the transfer channel entrance is located. Using the scale marks on the isolation tube, the depth of sludge in this position was ultimately found to be 36.5 inches, similar to what was found in 1999, approximately 37.5 inches. As in the past campaign, as the isolation tube was inserted in the bulk sludge, it was noted that there was significant physical resistance encountered at 13 inches and 10 inches from the floor, indicating that the sludge may have a crusty or hardened nature in this area. With final placement, it was believed that the isolation tube was successfully firmly seated on the pit floor (i.e., the isolation tube has a beveled lower edge to help seat onto the floor surface).

Pulling the Core Sample. With the isolation tube in-place (and with the sampling equipment and basin prepared), the Sampling Team (composed of Duratek, K Basin, and PNNL staff) pulled the core sample over a 2-day period, ultimately working the sampling system extraction tube down the isolation tube from above the sludge surface to the basin floor. It required three pairs of primary sample bottles to pull all the sludge solids. Table A1 provides a summary of these bottles. The first two pairs were pulled December 13, 2003, and the last pair was pulled December 19, 2003. The period between sampling activities allowed for shipment of a portion of the sample bottles, so needed shielded containers were available for the remaining two primary bottles. The Sampling Team noted that there was some resistance felt on the extraction tube that caused the sampling to go slower through the lower portion of the core sample (where the resistance had been encountered during insertion of the isolation tube).

WHC-SD-SNF-SDD-003, Rev. 0-A

Figure 6. Schematic of Floor Sludge Sampler.

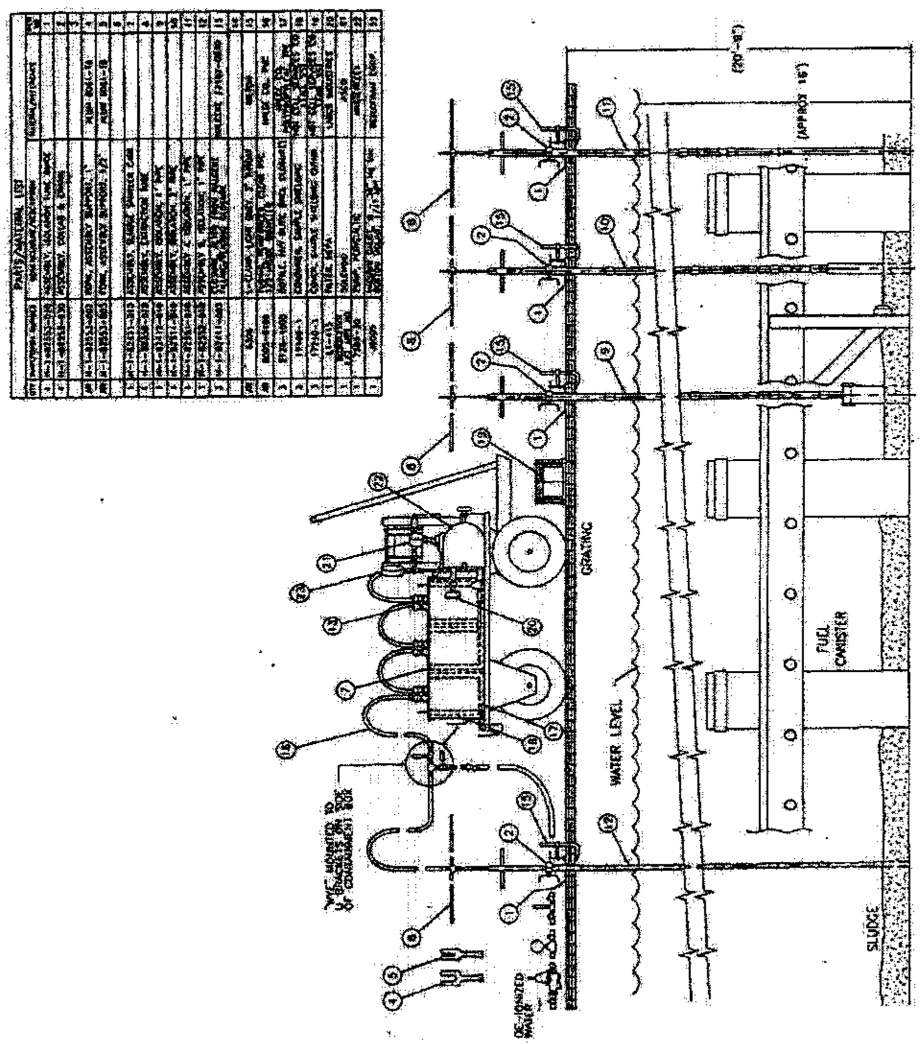

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Figure A.1. Overview of Sampling Equipment

Figure A.2. Sampling Cart with Sample Bottles In-Place in Shielded Containers

A.3 Decanting and Shipping Samples

After each pair of primary bottles was filled with carrier water and sludge solids, the bottles were prepared for shipment to the laboratory using the PAS-1 Cask. As noted previously, part of this preparation was the need to decant each primary bottle, providing the required 2-L head space. In each case, the carrier water was decanted from the primary bottle to a similar 4-L "decant" bottle, numbered and handled with similar rigor as the primary bottles. Table A1 indicates the resulting decant bottles.

Before shipment, each primary and decant bottle was inspected (the polypropylene bottles are semi-transparent) to estimate the level of solids present and to measure for dose rate, Figure A.3. For each decant bottle, a decision was made (as per the Test Plan) if the bottle should be shipped to the laboratory (did the bottle contain significant solids) or discarded (if the bottle contained essentially only carrier water). For the first pair of primary bottles, decanting was done relatively soon (within 20 minutes) after the samples were pulled, which did not allow much time for the fine suspended solids to settle, it was judged that these bottles should be shipped to the laboratory since they appeared to contain solids of interest. The decant bottles from the remaining two pairs of primary bottles were inspected and did not contain significant solids to justify additional shipments to the laboratory, but were returned to the basin pool.

Table A.1. Summary of Primary and Decant Bottles Resulting from Sampling KE NLOP December 2004

Sample Bottle Designation	Date Taken	Minimum Observed Volume of Solids[(a)], mL	Maximum Measured Dose, mr/h on contact (window open measurement includes beta/gamma contribution)	Date Shipped to Lab or Discarded	Comment[(b)]
KE-20-A	Dec 13, 2003	1300	80	Dec 17, 2003	From top ~12" of core sample
KE-20-B	Dec 13, 2003	500	35	Dec 17, 2003	From top ~12" of core sample
KE-20-D	Dec 13, 2003	750	32	Dec 19, 2003	From middle ~12" of core sample
KE-20-E	Dec 13, 2003	200	20	Dec 19, 2003	From middle ~12" of core sample
KE-20–G	Dec 19, 2003	500	220	Dec 21, 2003	From bottom ~12" of core sample
KE-20-H	Dec 19, 2003	250	120	Dec 21, 2003	From bottom ~12" of core sample
KE-20-AD	Dec 13, 2003	200	8	Dec 23, 2003	Two liter decant from KE-20-A
KE-20-BD	Dec 13, 2003	< 50	8	Dec 23, 2003	Two liter decant from KE-20-B
KE-20-DD	Dec 13, 2003	Trace	6	Discarded on 1/14/04	Two liter decant from KE-20-D
KE-20-ED	Dec 13, 2003	Trace	6	Discarded on 1/14/04	Two liter decant from KE-20-E
KE-20-GD	Dec 19, 2003	Trace	7	Discarded on 1/14/04	Two liter decant from KE-20-G
KE-20-HD	Dec 19, 2003	Trace	8	Discarded on 1/14/04	Two liter decant from KE-20-H

(a) Estimates made during observations at K Basins, solids not necessarily fully settled.

(b) The top of the sample extraction tube was clamped 50" above the top of the isolation tube [the lower tip of the extraction tube calculated to be bout 42 1/4" above the floor—sludge depth was ultimately found to be at 36-1/2" at this location]. After collecting samples KE-20-A and KE-20-B, the top of the extraction tube to isolation tube was 32" [the lower tip of the extraction tube calculated to be 24 ¼" from the floor]. After collecting samples KE-20-D and KE-20-E, the new separation was 20" [the lower tip of the extraction tube about 12.25" above the floor]. On December 19, 2003, the sludge depth (which was readily discernible) was observed to be 36 1/2" on the isolation tube scale. After samples KE-20-G and KE-20-H were collected, the final distance between the top of the extraction tube and the top of the isolation tube was 7 ¾". At this point the extraction tube nozzle was resting on the pit floor.

Once the sample bottles were decanted and the shipping lids installed, the bottles were placed in a controlled holding area and ultimately placed in special shielded shipping containers. These shielded shipping containers were subsequently loaded in the PAS-1 Cask and shipped two at a time to the 325 Building Laboratory for recovery, consolidation, and analyses.

Figure A.3. Decanted Primary Sample Bottle

A.4 Summary Observations

The following are the summary observations from the sampling activity:

- Insertion of the isolation tube into the sludge indicated that there was some physical resistance encountered in the bulk sludge accumulation of the KE NLOP in the region at 13 inches and 10 inches off the floor. This had been generally noted before as a region of crusty sludge material.

- The depth of sludge in the sampled location was measured on the isolation tube scale as 36.5 inches (compared with values in this general area of 37.5 inches measured in 1999 and 33 inches implied from measurements in 1993). The sludge in the KE NLOP required significant time (days) to settle sufficiently to allow measurement of the depth of the sludge surface using the isolation-tube depth scale on the underwater video—initial estimates were on the order of about 40 inches because of a cloudy suspended layer of sludge near the surface.

- Table A1 provides the observations from the primary and decant sample bottles.
- One day after collecting the initial pairs of primary sample bottles, the apparent volume of the solids layer had consolidated to roughly 50% of the apparent volume on the day of sampling. This consolidation resulted in significant increases to the dose rates measured on contact from the bottom of the bottles. (This observed behavior may in-part explain the lower dose and larger volume of solids noted initially for the 1999 samples from the KE NLOP [Pitner 1999] compared to the volume that was ultimately recovered from the sample bottles in the laboratory.)
- The Sampling Team did an excellent job—successfully obtaining and shipping the sample material as required by the Test Plan (Delegard 2003), meeting all requirements and safely completing the activity under an extremely short schedule on December 23, 2003.

A.5 References

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Appendix B

Sample Receipt, Inspection, and Compositing

Appendix B: Sample Receipt, Inspection, and Compositing

Sample Receipt

Eight sludge samples were received from the KE Basin in late December 2003. The samples were obtained, pair-wise, from the KE North Load Out Pit (NLOP) in the order KE-20-A and KE-20-B (collected from the top of the NLOP solids layer), KE-20-D and KE-20-E (from the middle of the NLOP solids layer), KE-20-G and KE-20-H (from the bottom), and KE-20-AD and KE-20-BD (which were decantates from KE-20-A and KE-20-B containing appreciable quantities of flocculent solids).

Each 4-L-thick walled sampling bottle originally contained 4-L total volume but had been gravity settled, and the supernatant solution decanted at the KE Basin to a 2-L level were pre-marked on each bottle. The respective decantates collected in similar 4-L bottles were labeled the same as the source bottle but with the addition of the letter D at the end of the sample number (e.g., the decantate from KE-20-A was designated KE-20-AD). Because the decantates from KE-20-D, KE-20-E, KE-20-G, and KE-20-H contained little solid, they were not shipped from the KE Basin to the 325 Laboratory and instead were returned to the KE NLOP waters. Refer to Appendix A for more details on the sampling of the KE NLOP sludge.

The sample receipt dates and estimated settled sludge volumes in each container are shown in Table B.1. As seen in Table B.1, settled sludge comprised no more than 15 volume percent of any sample and, over all eight samples, was only about 9 volume percent of the total received volume.

Table B.1. Sludge Sample Receipt and Compositing

Sample Number	Receipt Date	Side Dose Rate, mrem/h, at Contact / 30 cm[a]	Sludge Volume Est., mL	Sample Bottle Weight, g			Sludge Composite	
				Gross	Empty	Net	Weight, g	Volume, mL
KE-20-A	17 Dec 03	80 / 8	250	2767.53	742.71	2024.82	592.93	570
KE-20-B	17 Dec 03	38 / 4.4	200	2753.96	837.69	1916.27		
KE-20-D	19 Dec 03	31 / 3.7	250	2812.54	837.25	1975.29	294.50	355
KE-20-E	19 Dec 03	14 / 1.6	100	2796.02	718.03	2077.99		
KE-20-G	21 Dec 03	110 / 9	300	3056.72	753.87	2302.85	986.30	675
KE-20-H	21 Dec 03	30 / 5	200	2823.27	727.21	2096.06		
KE-20-AD	23 Dec 03	8 / 1.7	100	2796.18	711.27	2084.91	290.16	250
KE-20-BD	23 Dec 03	1.8[b] / 1.6[b]	10	2521.49	713.79	1807.70		
Total sludge composite							2163.89	1850
Decanted sludge composite (density = 1673.93 g/1350 mL = 1.24 g/mL)							1673.93	1350

(a) Window-closed CP readings.
(b) Similar due to background.

The eight sample containers were brought individually into the open-face hood adjacent to the glovebox in Room 528 of the 325 Laboratory. Each container was photographed (Figures B.1 through B.4). The presence of smearable external contamination on containers KE-20-E and KE-20-BD prevented the removal of their plastic bag coverings until their loading into the glovebox and thus prohibited unobstructed views of these two bottles themselves. While in the open-face hood, dose rates were measured from the side at the sludge/water interface. These dose rate data are given in Table B.1. Each as-received sample was closely inspected, but none showed evidence of gassing or bubble formation.

Sample Compositing

The eight sample containers then were loaded into the glovebox and weighed immediately. The composite sludge from the KE NLOP then was prepared. None of the containers showed pressurization (e.g., by gassing or bubbling) when the caps were removed.

To evaluate possible layering of sludge in the KE NLOP, the sludges from the paired samples first were combined according to how they were collected (i.e., KE-20-A and -B were collected, then KE-20-D and -E, KE-20-G and -H, and KE-20-AD and -BD). For example, to do this pair-wise collection for KE-20-A and KE-20-B, the supernatant solution from sample KE-20-A was decanted to the level of the settled solids and the decantate collected. The settled solids in KE-20-A then were slurried by swirling and transferred into the composite receiving container. The composite was collected in a 2-L polypropylene wide-mouth bottle. In a similar manner, the supernatant solution was decanted from KE-20-B and the KE-20-B settled solids slurried and transferred into the same composite container as used for the slurried solids from KE-20-A. The composite KE-20-A and KE-20-B slurried-solids volume and mass were measured and a ~5 mL subsample taken for analysis. The masses of the empty KE-20-A and -B containers then were measured, and the decantates recovered from samples KE-20-A and KE-20-B were combined in container KE-20-A.

The decantation, sludge slurry transfer, and subsampling steps were repeated for the remaining three sample pairs, and the decantates for the pairs were collected, respectively, in containers KE-20-D, KE-20-G, and KE-20-AD. The container gross, tare, and net contents weights, the volumes and masses of the sample pairs, and the overall composite sludge are shown in Table B.1. At this point, the total collected sludge volume was 1850 mL, and the total mass was 2163.89 g.

The composite sludge was allowed to settle overnight (Figure B.5). After overnight settling, 500 mL of clear supernatant solution was decanted to give a final settled sludge volume of 1350 mL (the top ~25 mL being clear) and a total mass of 1673.93 g. The settled-sludge density therefore was 1673.94 g/1350 mL or 1.24 g/mL. These and subsequent manipulations showed that about ⅓ of the settled-sludge volume was sand, and this sand fraction settled rapidly after agitation. The top ⅔ was a brown, easily suspended floc. The 2-L composite container was 115 mm in diameter and the sample depth about 128 mm when holding 1350 mL.

Samples were withdrawn from the well-mixed composite at this point to leave 1210 mL of sludge (i.e., 1350 mL – 1210 mL = 240 mL of settled sludge was withdrawn). The 1210 mL of settled sludge was left undisturbed for another 6 days and was observed to have settled further to show the interface of the settled solid to clear liquid at the 960-mL level (i.e., 1210 mL – 960 mL = 250 mL of clear supernate). By extension, if the original 1325 mL of settled sludge observed after 1 day of settling had been allowed a further 6 days of settling, the settled sludge volume (assuming negligible additional sludge compression by the added sludge depth) would have been 1070 mL [1350 mL × (960 mL settled/1210 mL total)]. If the supernatant (density of 1.00 g/mL) had been discarded at this point, the remaining settled sludge would have had a bulk density of 1.30 g/mL.

However, to keep the same solid/liquid basis as the original sampling, the sludge and supernatant solution were re-agitated before all subsequent samplings for analysis or testing. The settling observations are summarized in Table B.2.

Table B.2. Settling of KE NLOP Composite Sludge

Time (days)	Total Volume, mL	Settled Sludge Volume, mL
0	1350	1325
6	1210	960
6[a]	1350	1070
(a) Assuming settling of entire sample had occurred.		

The 2-L composite container was 115 mm in diameter, with a 2.0-mm bottom thickness and a 1.5-mm wall thickness. The dose rates on the bottle at contact and at 30-cm distance were measured at the bottom and side of the bottle (centered on the settled sludge) through a 15-mil Hypalon glovebox glove. The bottle contained 1200 mL of settled sludge when the dose-rate measurements were made, the balance having been taken for analytical and gas-generation testing. The settled sludge was about 115 mm deep in the bottle. The dose rates are summarized in Table B.3.

Table B.3. Dose Rate of KE NLOP Sludge Composite

Position	Dose Rate, mrem/h	
	Contact	30-cm
Bottom	420	50
Side	350	36
Uncorrected "window-closed" CP readings.		

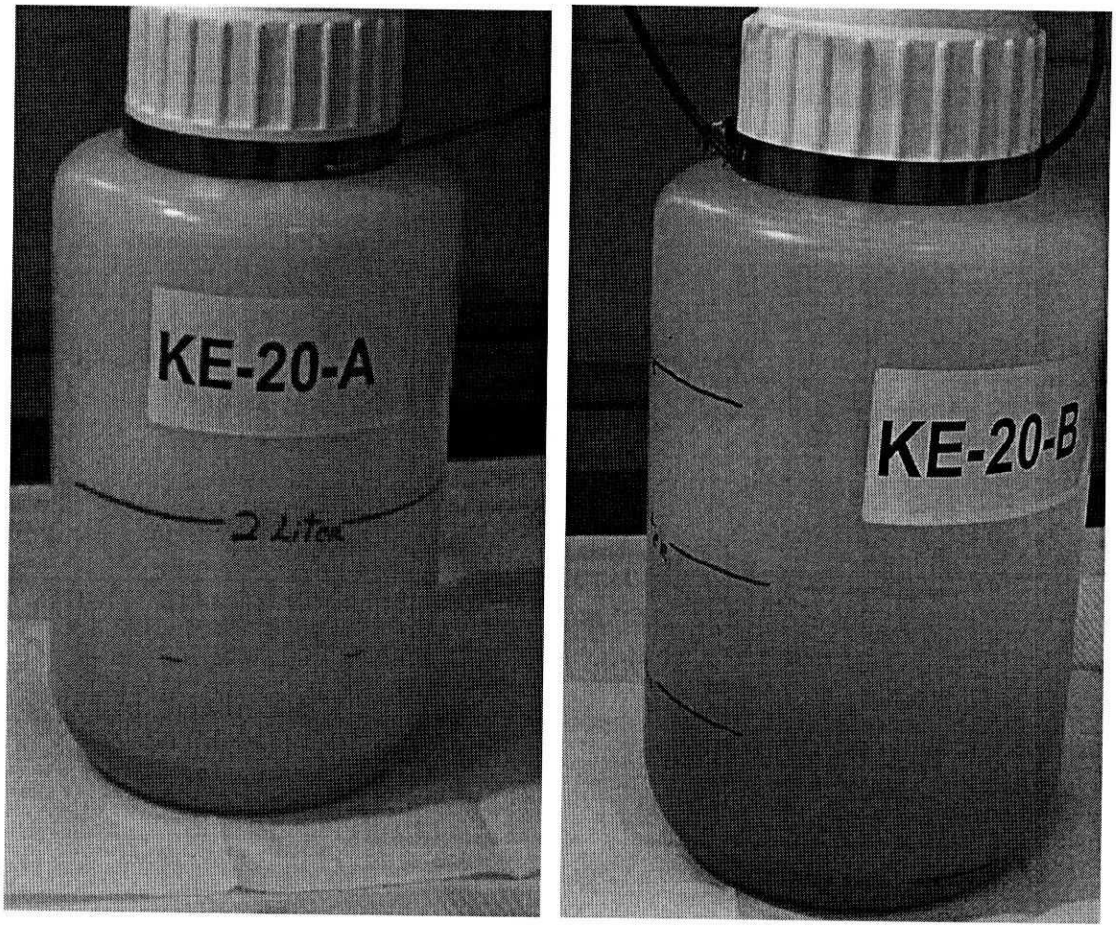

Figure B.1. **Samples KE-20-A and KE-20-B**

Figure B.2. Samples KE-20-D and KE-20-E

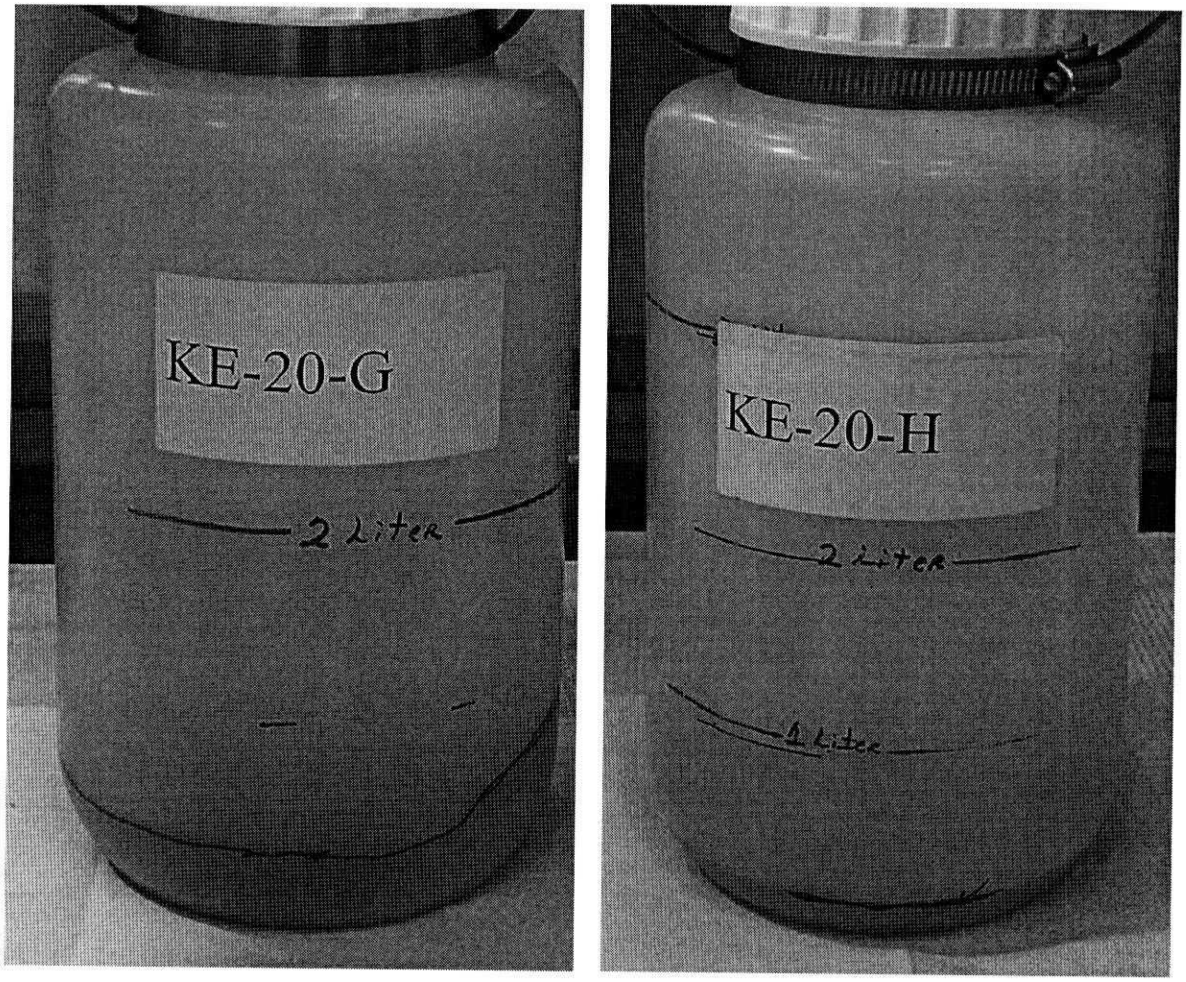

Figure B.3. Samples KE-20-G and KE-20-H

Figure B.4. Samples KE-20-AD and KE-20- BD

Figure B.5. KE NLOP Sludge After Overnight Settling.
Note solution level at red mark (1850 mL) and settled sludge at about 1325 mL.
Level marks in 100-mL increments with top marked level at 2000 mL.

Appendix C

Physical-Property Measurements

Appendix C: Physical-Property Measurements

Physical properties (density and settling rate) of the settled sludge were measured in the glovebox of Room 528 at the 325 Laboratory. This work was conducted under the Test Instruction 46857-TI02, "Preparation of KE NLOP Composites and Samples."

As noted in Appendix B, the density of the settled sludge was found to be 1.24 g/mL. The density was determined by weighing the collected settled sludge in the composite container. The collected composite sludge volume was estimated based on volume level marks drawn on the container. The level marks were made based on adding 100-mL increments of water to the container and marking the levels reached by each successive increment.

The composite sludge density was re-evaluated by weighing 10-mL increments of well-mixed sludge into a plastic 10-mL syringe. The end of the syringe was cut off, and the cut end was beveled to give a smooth edge. The 10-mL level was calibrated by adding 10.0 g of water (density of 1.00 g/mL) to the open-end-up syringe with the plunger withdrawn up the syringe barrel. The plunger was pushed upwards until the water level reached the open end, and the plunger position was marked. The syringe prepared this way functioned as a 10-mL graduated cylinder with the additional capability to discharge all of its contents for density re-measurements and for sampling for subsequent radiochemical analysis.

To make the density determinations, the syringe was tare-weighed, the plunger was withdrawn to the 10-mL mark, the open end was placed upwards, and, using a large transfer pipet, a sludge sample was withdrawn from the composite container while the sludge contents were being aggressively stirred. As seen in Table C.1, the results of the five determinations of the sludge density agree with the 1.24 g/mL sludge density estimated from the mass and volume of the entire collected composite. The variability of the five 10-mL basis density measurements is about 1.2%, relative.

Table C.1. Settled Sludge Density

Measurement	Density, g/mL
1	1.259
2	1.234
3	1.250
4	1.222
5	1.238
Average	1.241
Std. Dev. ($\pm1\sigma$)	0.014

The settling rate of the dilute sludge also was measured. First, 50 mL of well-mixed composite sludge was added into a 250-mL graduated cylinder. Decant water from KE-20-A then was added to reach a 250-mL total volume. The sludge was mixed thoroughly with the decant water in the graduated cylinder, and then the cylinder was placed on the glovebox floor and the settling behavior assessed as a function of time.

The sand in the sludge settled rapidly (within a few seconds) to the bottom of the graduate. The flocculent brown solids settled more slowly, but even after 6 days had not settled back to the original settled sludge volume (Figure C.1).

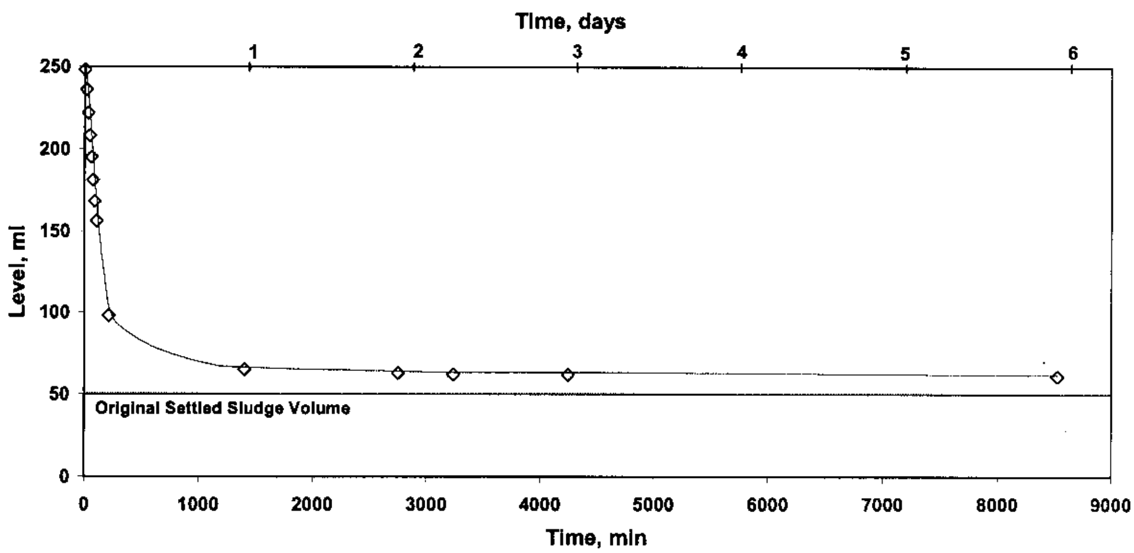

Figure C.1. Settling of Sludge/Supernatant Solution Mixture

Appendix D

Radiochemical Analyses and Data Tables

Appendix D: Radiochemical Analyses and Data Tables

Chemical and radiochemical analyses of the settled sludge and of the supernatant solution were measured in the glovebox of Room 528 and in the Analytical Services Operations (ASO) of the 325 Laboratory. The samplings for analysis and pH measurements were conducted under the Test Instruction 46857-TI02, "Preparation of KE NLOP Composites and Samples." The sample-preparation digestions and subsequent chemical and radiochemical analyses were performed according to the general directions in the Test Plan ("Bench-Scale Test Plan to demonstrate production of WIPP-Acceptable KE NLOP Sludge Waste Forms at the 325 Building") and under the specific procedures outlined in Table D.1.

Table D.1. Analytical Procedure Listing

Sample Prep.	Analyte	Procedure Title	Procedure Number
As rec'd.	pH	Test Instruction	TI 46857-TI02
As rec'd.; 2.0-mL aliquots	Density, ρ	Test Instruction	TI 46857-TI02
	GEA	Gamma Energy Analysis (GEA) and Low-Energy Photon Spectrometry (LEPS)	RPG-CMC-450
As rec'd.; 15-g aliquots	H_2O	Water Determination by Weight Loss on Drying	PNL-ALO-504
Sample residue from H_2O analyses fused and dissolved in acid; Solubilization of Metals from Solids Using Pyrosulfate Fusion (Test Plan) and KOH-KNO_3 Fusion, PNL-ALO-115 Sample supernate, received only a dilution for applicable analyses.	GEA	Gamma Energy Analysis (GEA) and Low-Energy Photon Spectrometry (LEPS)	RPG-CMC-450
	Pu	Pu and Am/Cm derived from the Alpha Energy Analysis (AEA) results.	RPG-CMC-422
	Am/Cm		
	^{90}Sr/Y	^{90}Sr/Y is inferred based on results of the GEA and Total Beta	N/A
	U by KPA	Uranium by Kinetic Phosphorescence Analysis	RPG-CMC-4014
	AT	Total Alpha and Beta Analysis	RPG-CMC-408
	AEA	Solutions Analysis: Alpha Spectrometry	RPG-CMC-422

pH Measurements

The pH measurements were performed using a Corning wand-type pH meter. The meter was calibrated using fresh buffer solutions, and the check measurements of pH 4.00, 7.00, and 10.00 buffers were within 0.04 pH units of the target value. The pH of the supernatant solutions from combined samples KE-20-A and -B (in Vessel KE-20-A), KE-20-D and -E (in Vessel KE-20-D), KE-20-G and -H (in KE-20-G), and KE-20-AD and -BD (in KE-20-AD) were measured. The pH of the composite KE NLOP sludge also was measured. The pH values, summarized in Table D.2, vary over about 0.8 pH units for the supernatant solutions. The relatively large pH span likely is because ion exchange purification of the supernatant waters removed all buffering ions. The settled sludge pH of 8.31 is similar to the pH 8.34 value observed for FE-3, a prior composite KE NLOP sludge (Table 1.3). In contrast with the unbuffered KE NLOP supernatant solution, the mineral solid-in-water KE NLOP sludge can maintain stable pH-buffered conditions by hydrogen ion (H^+) exchange on the hydrous solids' surfaces.

Table D.2. Solution and Settled Sludge pH

Sample	Measured pH
pH 4.00 buffer	4.03
pH 7.00 buffer	7.01
pH 10.00 buffer	10.04
KE-20-A	7.60
KE-20-D	7.16
KE-20-G	7.95
KE-20-AD	7.36
KE NLOP Sludge	8.31

Sampling for Chemical and Radiochemical Analyses

Four samples were retrieved for priority chemical and radiochemical analyses. Three of the samples were taken from the composited settled KE NLOP sludge, and one sample was supernatant solution taken from Vessel KE-20-A. In addition, duplicate sludge samples were taken from the KE-20-A and -B, -D and -E, -G, and -H, and -AD and -BD interim sludge composites (see Appendix B on the collection of the intermediate sludge layers). The sample sources, subsample names, and subsample quantities are shown in Table D.3. Accurately measured sample volumes (10.0 or 2.0 mL) were delivered to sample vials by adding increments of well-mixed sludge or supernatant solution into tare-weighed plastic volume-calibrated syringes.[a] The syringes were discharged into the sample vials, and the syringes were re-weighed to determine, by difference, the delivered weights.

(a) To prepare the measuring syringes, the ends of the barrels of ordinary plastic 10-mL and 5-mL syringes were cut off and the cut ends beveled smooth. The respective 10-mL and 2-mL levels were calibrated by adding 10.0 or 2.00 g of water (density of 1.00 g/mL) to the open-end-up syringes with the plungers withdrawn up the syringe barrel. After adding the precise water mass, the plungers were pushed upwards until the water level reached the open syringe end. The plunger position at that point was marked to show the 10.0- or 2.0-mL levels. The sludge was added to the tare-weighed end-up syringes (with plungers at the set 2.0- or 10.0-mL marks) to the upper level and the syringes re-weighed. The loaded syringes then were discharged into the sample vials. The syringes prepared in this way were capable of discharging nearly all of the sludge contents for subsample preparation and left little residual sludge behind in the syringe. Any residual sludge was measured by re-weighing the emptied syringe.

Table D.3. Chemical and Radiochemical Sample Aliquots

Source	Sample Identification	Sample Quantity	
		mL	g
KE NLOP Composite	KENLOP-1[a]	10.0	12.38
	KENLOP-A[a]	2.0	2.45
	KENLOP-B[a]	2.0	2.40
Supernatant from KE-20-A &-B	KENLOP-Liq[a]	2.0	1.96
Sludge from KE-20-A & -B	KENLOP-AB1	2.0	1.98
	KENLOP-AB2	2.0	2.00
Sludge from KE-20-D & -E	KENLOP-DE1	2.0	2.18
	KENLOP-DE2	2.0	2.21
Sludge from KE-20-G & -H	KENLOP-GH1	2.0	2.39
	KENLOP-GH2	2.0	2.53
Sludge from KE-20-AD & -BD	KENLOP-DS1	2.0	2.00
	KENLOP-DS2	2.0	2.00

(a) Samples for priority analysis.

<u>Chemical and Radiochemical Analyses and Results</u>

Chemical and radiochemical analyses were performed for the subsamples shown in Table D.3. The highest priority was accorded to the KENLOP-1, KENLOP-A, and KENLOP-B composite sludge and KENLOP-Liq supernatant solution subsamples. The results presented here are confined to the findings for these four priority subsamples.

The first step in the analytical sequence was to perform gamma energy analyses (GEA) of the intact subsamples. The as-prepared subsample geometries met the set geometries needed for GEA.

Three accurately weighed ~1-gram portions then were drawn from subsample KENLOP-1 and were dried to constant weight in a 105°C oven. The weight loss at 105°C was ascribed to water. After drying, one portion was reserved for X-ray diffractometry (not yet performed) and the other two portions underwent sequential digestions in acid (mixed nitric/hydrochloric), fusion of the acid digest residue in potassium pyrosulfate, and fusion of the potassium pyrosulfate residue in potassium hydroxide according to established ASO procedures (Table D.1). No residue remained after the final (potassium hydroxide) fusion.

Aliquots from each of the digestates were analyzed for total beta activity, total alpha activity, activity analyses of isotopes by their alpha energies (alpha energy analysis or AEA), and uranium (by kinetic phosphorescence). The primary alpha energy peaks registered by AEA are due to $^{239,240}Pu$ and ^{238}Pu,^{241}Am with lesser activity due to $^{243,244}Cm$. The supernatant solution (KENLOP-Liq) likewise was analyzed for total beta activity, total alpha activity, AEA, and uranium.

The weight-based analyte concentrations in the acid and two fusion digests of the composite settled sludge were summed to determine the total concentrations of the respective analytes. The individual results of the analyses for the acid and two fusion digests, presented in Table D.4, show that the initial acid digest removed 99% or more of the respective analytes.

Table D.4. Analytical Results for KE NLOP Sludge Digests

Analyte	Concentration, μCi/g settled sludge					
	KENLOP-1, Rep-1			KENLOP-1, Rep-2		
	Acid	$K_2S_2O_7$	KOH	Acid	$K_2S_2O_7$	KOH
$^{239,240}Pu$	1.72E+0	4.98E-4	3.65E-5	1.79E+0	4.15E-4	3.46E-5
^{238}Pu, ^{241}Am	1.59E+0	4.74E-5[(a)]	4.11E-6[(a)]	1.74E+0	3.64E-5[(a)]	4.30E-6[(a)]
$^{243,244}Cm$	3.64E-3			4.22E-3		
Total Alpha	3.75E+0			3.69E+0		
Total Beta	1.13E+1	1.07E-1		1.10E+1	8.54E-2	
^{90}Sr[(b)]	7.81E-1	1.12E-3		9.60E-1	2.95E-3	
Uranium, μg/g	5.68E+3	6.00E-1		5.33E+3	3.60E-1	
^{60}Co	5.80E-2	3.63E-3	1.28E-5	5.66E-2	2.80E-3	1.41E-5
^{137}Cs	7.77E+0	9.94E-2	1.38E-2	7.32E+0	7.54E-2	1.56E-2
^{154}Eu	1.11E-1			1.08E-1		
^{155}Eu	2.84E-2			2.60E-2		
^{241}Am	1.77E+0	4.43E-4		1.57E+0		
^{125}Sb		7.85E-4	4.75E-4		1.30E-3	4.79E-4
Sum gamma	9.74E+0	1.04E-1	1.43E-2	9.08E+0	7.95E-2	1.61E-2

(a) ^{238}Pu only.
(b) ^{90}Sr inferred to be half of the difference between the Total Beta activity and the sum of the gamma activity. The other half of the activity difference is due to ^{90}Y.
Blank spaces are below detection limits.

The overall results of the sample analyses are shown in Table D.5. The following general observations are drawn from these data:

- ^{137}Cs dominates the high energy gamma activity in the sludge; ^{60}Co also provides much of the high energy gamma radiation.
- The settled sludge contains 0.55 wt% total uranium.
- Though the solution comprises nearly ⅔ of the settled sludge mass, it contains very little of the radioactivity or uranium.
- The settled sludge is transuranic with total alpha activity of 3720 nCi/g or 37-times the TRU limit of 100 nCi/g.
- Aside from ^{60}Co and ^{154}Eu (which have half-lives of 5.27 years and 8.59 years, respectively), the concentrations of uranium and radionuclides found in the present KE NLOP dry sludge solids are similar to those reported for the KE NLOP sample FE-3 shown in Tables 1.2 and 1.3.

Table D.5. Analytical Results for KE NLOP Sludge and Supernatant Solution

Analyte	Concentration, µCi/g									Settled Sludge Concentration, µCi/mL[(b)]	% of Analyte in Solids[(c)]
	Settled Sludge					Solution			Dry Sludge Solids[(a)]		
	KENLOP-1		KENLOP-A	KENLOP-B	Avg.	KENLOP-Liq		Avg.			
^{60}Co	7.00E-2		6.83E-2	6.43E-2	6.75E-2	2.33E-5		2.33E-5	1.79E-1	8.37E-2	99.98
^{137}Cs	7.81E+0		5.72E+0	7.07E+0	6.87E+0	4.09E-2		4.09E-2	1.82E+1	8.52E+0	99.63
^{154}Eu	1.32E-1		1.31E-1	1.20E-1	1.28E-1	<3.E-5		3.00E-5	3.39E-1	1.58E-1	99.99
^{155}Eu	3.04E-2		3.37E-2	3.35E-2	3.25E-2	<2.E-4		1.50E-4	8.61E-2	4.03E-2	99.71
^{241}Am	1.77E+0		1.67E+0	1.53E+0	1.66E+0	<4.E-4		4.00E-4	4.40E+0	2.06E+0	99.98
	Rep-1	Rep-2			Avg.	Rep-1	Rep-2	Avg.			
$^{239,240}Pu$	1.72E+0	1.79E+0			1.76E+0	1.47E-4	1.36E-4	1.42E-04	4.66E+0	2.18E+0	99.99
^{238}Pu,^{241}Am	1.59E+0	1.74E+0			1.67E+0	1.32E-4	1.20E-4	1.26E-04	4.42E+0	2.06E+0	100.00
$^{243,244}Cm$	3.64E-3	4.22E-3			3.93E-3	<5.E-7	<4.E-7	<5.E-7	1.04E-2	4.87E-3	>99.99
Total Alpha	3.75E+0	3.69E+0			3.72E+0	2.92E-4	2.76E-4	2.84E-04	9.87E+0	4.61E+0	100.00
Total Beta	1.14E+1	1.11E+1			1.12E+1	5.27E-2	5.22E-2	5.25E-02	2.97E+1	1.39E+1	99.71
^{90}Sr[(d)]	7.75E-1	9.55E-1			8.65E-1	5.90E-3	5.60E-3	5.75E-03	2.29E+0	1.07E+0	99.59
U, µg/g	5.68E+3	5.33E+3			5.51E+3	1.64E+1	1.66E+1	1.65E+1	1.46E+4	6.83E+3	99.81
Water, wt%	61.71	62.90			62.3						0.00

(a) Analyte concentrations in the sludge solids were determined by deducting the mass and analyte contributions of the solution from the respective settled sludge mass and analyte quantities. For example, there is 6.75×10^{-2} µCi ^{60}Co in one gram of settled sludge. One gram of settled sludge also contains 0.623 g of solution (settled sludge is 62.3 wt% water). The 0.623 g of solution contains ^{60}Co in the amount 0.623 g × 2.33×10^{-5} µCi ^{60}Co/g = 1.45×10^{-5} µCi ^{60}Co. The concentration of ^{60}Co in the sludge solids (0.377 g) in 1 gram of settled sludge is (6.75×10^{-2} µCi - 1.45×10^{-5} µCi) / 0.377 g = 1.79×10^{-5} µCi ^{60}Co/g.

(b) The settled sludge concentration in µCi/mL is calculated by multiplying the concentration, in µCi/g, by the settled sludge density of 1.24 g/mL.

(c) The percentage of analyte in the sludge solids was determined by deducting the contribution of the analyte found in the solution associated with the settled sludge from the total analyte found in the same quantity of settled sludge, dividing by the analyte quantity in the settled sludge, and multiplying by 100%. For example, as shown in footnote [a] above, one gram of settled sludge contains 6.75×10^{-2} µCi ^{60}Co and the associated solution contains 1.45×10^{-5} µCi ^{60}Co. The sludge solids therefore contain 100% × (6.75×10^{-2} µCi ^{60}Co - 1.45×10^{-5} µCi ^{60}Co)/ 6.75×10^{-2} µCi ^{60}Co = 99.98% of the ^{60}Co.

(d) ^{90}Sr inferred to be half of the difference between the Total Beta activity and the sum of the gamma activity. The other half of the activity difference is due to ^{90}Y.

Appendix E

Results of Initial Gas-Generation Testing

Appendix E: Results of Initial Gas-Generation Testing

E.1 Overview

Experimental measurements of sludge reaction rates and gas generation form the technical basis for sludge uranium metal content, uranium metal particle size and reaction enhancement factor values. Three phases, or series of gas-generation experiments, have been conducted and documented. The first test series (Series I; Delegard et al. 2000) focused on gas generation from KE basin floor and canister sludge (size-fractionated and unfractionated samples collected using a consolidated sampling technique (Baker et al. 2000). The second series (Series II; Bryan et al. 2001) examined the gas-generation behavior of KE Basin floor, pit, and canister sludge. Mixed and unmixed and fractionated KE canister sludge materials were tested, along with floor and pit sludge from areas in the KE Basin not previously sampled. The third series (Series III; Schmidt et al. 2003) examined the corrosion and gas-generation behavior from irradiated metallic uranium particles (fuel particles) with and without sludge addition. In the gas-generation testing series, sludge samples and irradiated metallic uranium fuel particles were introduced into reaction vessels, and in most cases, the samples were held at a series of controlled temperatures long enough for essentially complete oxidation of the uranium metal, and gas samples were periodically taken.

Because the focus of the SNF Sludge project has changed from an interim storage mission to near-term disposition to WIPP, additional gas-generation tests with KE North Load Pit (NLOP) are underway, and initial results are summarized here. Current plans call for the retrieval and solidification/stabilization of KE NLOP sludge as Contact Handled (CH) Transuranic (TRU) waste for disposition to WIPP. Near-term disposition of the KE NLOP sludge is predicated upon the sludge being non-pyrophoric and exhibiting a very low hydrogen gas-generation rate (from uranium metal water reaction). Gas-generation testing (Bryan et. al 2001) conducted with a single consolidated NLOP sludge sample collected in 1999 indicated that the sludge contained very little uranium metal (i.e., 0.0013 wt% -settled sludge basis). However, to gain additional confidence on the low uranium metal content of the NLOP sludge, additional gas-generation testing is underway, using NLOP sludge collected in December 2003. Additionally, the effects of free/drainable water removal and solidification matrices (e.g., grout and Nochar®) on the gas-generation rate of the NLOP sludge are also being examined. If significant quantities of uranium metal are present, free/drainable water removal and solidification will likely inhibit the reaction between uranium metal and water.

E.2 Test Objectives

The overall goal for this testing is to collect gas-generation rate and composition data under known conditions to better understand the quantity and reactivity of the metallic uranium present in the KE NLOP sludge. Specific objectives for this testing include:

- Verify that the KE NLOP sludge is non-pyrophoric [contains less than 1 wt% pyrophoric material (i.e., uranium metal)]
- Determine the hydrogen generation rate and uranium metal content in KE NLOP sludge

- Determine the effect of free/drainable water removal on the hydrogen generation rate of KE NLOP sludge

- Determine the effect of a grout matrix on the hydrogen generation rate of KE NLOP sludge

- Determine the effect of the Nochar® matrix on the hydrogen (and hydrocarbon) generation rate of KE NLOP sludge

[Note that observation of any effects on the uranium metal-water reaction depends on uranium metal being present in the KE NLOP sludge.]

E.3 Summary of Initial Test Results

Tests to meet these objective were initiated on January 9, 2004 (i.e., tests with sludge and water only). Gas generation has been observed (i.e. pressure in reactor headspaces has increased) and the gas was sampled on January 14, 2004. The gas-generation tests with various waste forms (dewatered sludge, grout, Nochar) were initiated on January 19, 2004. Because the hydrogen gas-generating reaction of uranium metal with water is relatively slow, the full performance of the test specimens will not be known until after January 19, 2004. Ultimately, the tests conducted at 95°C (sludge and water only) will allow estimates of the concentration of uranium metal contained in the sludge.

Based on the results from the initial test interval (11 hours at 95 and 60°C) with the sludge and water only tests, the following observations and conclusion can be made:

- It is highly unlikely that KE NLOP sludge will be designated as being Pyrophoric material (> 1 wt% pyrophoric material). If the KE NLOP sludge contained 1 wt% uranium metal particles (assuming 500 μm diameter spheres), using the SNF Project rate equation (uranium metal in oxygen-free water) with a rate enhancement factor of 1, a hydrogen generation rate of 580 mL-H_2/kg-settled sludge-day would be expected at 95°C. This rate is 290 times greater than the initial measured rate (at 95°C), 2.0 mL-H_2/per kg-settled sludge/day.

- During the initial test interval (111 hours), at 95°C, the total gas-generation rate was 39 mL total gas per kg-settled sludge/day (48 mL total gas per liter-settled sludge-day). Based on the mass spectroscopy analysis, only ~5% of the total gas generated was hydrogen. The balance of the generated gas consists of mostly CO_2 (~95).

- The gas-generation-rate profile (total gas generation vs. time) shows that after about 50 hours at 95°C, the rate dropped to essentially zero, indicating reactants were largely depleted.

- During the initial 111-hour test interval at 60°C, the total gas-generation rate was 6.4 mL total gas per kg-settled sludge/day (8 mL total gas per liter-settled sludge-day). The composition of the gas generated at 60°C was essentially the same as that generated at 95°C.

- With the high CO_2 content in the generated gas, it may be improbable to achieve a gas mixture in any KENLOP sludge processing, transport, or storage operation.

- While the initial gas-generation rates for the 2003 KE NLOP sludge are low, they are significantly greater than those observed for the KE NLOP sludge collected in 1999. For the

1999 KE NLOP sludge sample (FE-3), while at 95°C for 473 hours, the total gas-generation rate was 6.1 mL total gas kg-settled sludge/day (9.7 mL total gas per liter-settled sludge-day) – with greater than 99% of the total gas being carbon dioxide (~0.36% of the total gas generated was hydrogen) (Bryan et. al 2001). The hydrogen gas-generation rate of FE-3 at 95°C for the 473 h test interval was 9.89 E-07 moles per kg-settled sludge/day (0.02 mL/kg-settled sludge/day). [Note the settled density of the FE-3 subsample used for gas-generation testing was 1.6 g/cm^3. Also, the FE-3 sample was stored at hot cell temperatures (32°C) for ~8 months before being used in the gas-generation test. Also note that the FE-3 sample was held at 90°C for about 300 hours before the test temperature was elevated to 95°C.]

- No quantifiable levels of fission product gases were detected during the initial test interval, which provides a preliminary indication that the sludge contains very little no uranium metal. In the previous gas-generation testing, with most K Basin sludges Kr and/or Xe fission product gases were measured, giving quantitative evidence of the corrosion of uranium metal (i.e., fission product gases remain trapped with the solid uranium metal matrix and do not react and are not significantly retained by the corrosion products in the sludge). Of all the sludge types previously subjected to gas-generation testing, Sample FE-3 (1999 KE NLOP sludge) and KC-6 (ion exchange resin beads collected from the floor of the KE Basin) were the only sludge types whose gas samples contained neither Kr nor Xe at detectible levels.

Results from gas-generation tests with dewatered KE NLOP sludge (no drainable liquids) and KE NLOP sludge solidified and grout and Nochar are not available, as these test were started on January 19, 2004.

E.4 Test Matrix, Materials, and Approach

This section describes the overall test approach and methods used for the KE NLOP sludge gas-generation testing.

E.4.1 Test Matrix and Specific Objectives

A total of six gas-generation tests, each with nominally 50 g settled KE NLOP sludge are being conducted. Three tests are being conducted with sludge and water only. In one test, moist sludge (i.e., drainable liquid has been removed) is being used. In the final two tests, the sludge has been solidified in grout and Nochar. After preparing sludge, the samples were placed into 220 mL reaction vessels. The reaction vessels were sealed, connected to the manifold system, and purged with neon gas to remove air. Next, the vessels were heated to the target conditions, and temperatures and gas pressures were monitored continuously. Initial gas samples from the sludge and water only tests were collected on January 14, 2003. Additional gas samples will be collected as described in the Test Plan. All gas samples will be analyzed via mass spectrometry. These tests are being conducted at PNNL's High-Level Radiochemistry Facility in the 325 Building (325A HLRF), 300 Area, in accordance the Test Plan (Delegard 2003) and Test Instruction (Schmidt 2003) and consistent with the sampling and analysis plan (Baker et al. 2000).

Table E.1 displays the test matrix that identifies test number, test identification, material (target sludge mass) and test conditions (vessel size, target temperature, start data, and target test duration).

Table E.1. Test Matrix for KE NLOP Sludge Gas-Generation Testing

Test No.	Test ID	As-Settled Sludge Type	As-Settled Sludge Mass g	Nominal Reaction Vessel Size mL	Matrix	Target Temp, °C	Start Date	Target Duration h
Tests with KE NLOP Sludge – Collected in 2003								
1	NLOP-U1	NLOP03	50	220	water	95	1-9-04	700
2	NLOP-U2	NLOP03	50	220	water	95	1-9-04	700
3	NLOP-Control	NLOP03	50	220	water	60	1-9-04	1000
4	NLOP-Moist	NLOP03	50	220	moist	60	1-16-04	1000
5	NLOP-Gt	NLOP03	50	220	grout	60	1-16-04	1000
6	NLOP-Nochar	NLOP03	50	220	Nochar	60	1-16-04	1000

Notes:
NLOP03 = KE North Loadout Pit Sludge collected December 2003

E.4.2 Specific Test Description/Objectives

Test 1, NLOP-U1. In this test, a 50 g aliquot of as-settled KE NLOP sludge was added to a reaction vessel. Additional sludge supernatant water was also added to maintain the sludge in a saturated state. The objective of Test 1 is to determine the total uranium metal content as rapidly as possible. Gas generating reactions (including reactions that generated CO_2) will be forced to completion. The results from this test will be used to interpret the results from Tests 2 – 6.

Test 2, NLOP-U2. Test 2 is a duplicate of Test 1. Measurement of the uranium metal content of the KE NLOP sludge is a critical measurement; therefore, a duplicate test is warranted.

Test 3, NLOP-Control. For Test 3, a reaction vessel was loaded in a manner identical to Test 1 and 2. However, whereas Tests 1 and 2 are being conducted at 95°C, Test 3 is being run at 60°C. Test 3 serves as a control to interpret the results of Test 4 to 6 (Test 3 - 6 will be conducted at the same temperature). Results from Tests 4 to 6 can be directly compared to the gas-generation rate profile of Test 3 to ascertain the effects of free/drainable water removal and solidification of the sludge.

Test 4, NLOP-Moist. In this test, drainable liquids were removed from a 50 g sample of as-settled KE NLOP sludge before loading the moist material into the reaction vessel. Appendix F provides details on the preparation of this waste form. This test examines the effect of sludge dewatering on the hydrogen generation rate of KE NLOP sludge (i.e., removal of drainable water is expected to inhibit the corrosion of uranium metal). The effect of sludge dewatering on other gas generating/consuming reactions will also be examined.

Test 5, NLOP-Grout. In this test, an aliquot of sludge was immobilized in Portland cement, with bentonite clay added to the matrix. After several days of curing, the grouted sludge was loaded into a reactor vessel. Appendix F provides details on the preparation of this waste form. This test examines the effect of a grout matrix on hydrogen generation rate of KE NLOP sludge. The effect of the grout matrix on other gas generating/consuming reactions will also be examined.

Test 6, NLOP-Nochar. In this test, an aliquot of sludge was immobilized in using a polymer solidification agent, Nochar. After several days of curing, the solidified sludge was loaded into a reactor vessel. Appendix F provides details on the preparation of this waste form. This test will examine the effect of the Nochar matrix on hydrogen generation rate of KE NLOP sludge. The effect of the Nochar on other gas generating/consuming reactions will also be examined.

E.4.3 Test Materials

A full sludge core was collected from the KE NLOP December 2003 (Appendix A), and was composited, homogenized, and subsampled. The mass and volume (as-settled sludge) of subsamples used for gas-generation testing were measured and radiochemical analyses were performed on the subsamples (Appendix B and C). For Tests 4 through 6, waste forms were prepared as described in Appendix F.

E.4.4 Reaction Vessels

Stainless steel reaction vessels were used (approximately 2 in. diameter and 4 7/8 in. tall, 220 mL nominal volume).

E.4.5 Reaction Atmosphere

Neon gas provides an inert atmosphere (i.e., oxygen free) for the gas-generation tests. Use of an oxygen-free atmosphere provides conditions that favor the uranium-metal reaction (i.e., hydrogen generations rates from this testing are expected to be conservative). Argon was not used because it served as an indicator of atmospheric contamination. After loading the reaction vessels and after collecting each gas sample, the vessels are purged multiple times with neon to remove air/oxygen from the system.

E.4.6 Test Temperatures

In the Series I gas-generation testing with KE canister sludge, (Delegard et. al. 2000), induction periods (time at target temperature before the onset of hydrogen gas generation/release) were observed. The induction periods were 1340 h, 205 h, and 27 h, at 40°C, 60°C and 80°C, respectively. Therefore, to obtain timely data, target test temperature in the current work are a minimum of 60°C.

For KE NLOP sludge metal determination (Tests NLOP-U1 and NLOP-U2), the target test temperature is 95°C (consistent with prior uranium metal content determination testing).

For gas-generation rate testing (with and without solidification matrices) the baseline reaction target temperature is 60°C. This temperature (60°C) is consistent with the maximum temperature during shipment to WIPP. While temperatures greater than 60°C may accelerate the testing, the results may not be reflective of expected storage and shipping conditions. However, if after some period of time (e.g., 500 hours) little or no gas generation is observed at 60°C, the test temperature may be increased.

Test temperatures also may be stepped successively to higher values to provide information on activation energies and provide information on the confounding effects of diffusion and underlying uranium-water reaction rates.

E.4.7 Test Duration

Previous gas-generation tests have ranged from 900 to 10,000 hours. It is expect that these test will continue for 1 to 2 months (700 to 1400 hours). Actual test durations will depend upon the gas-generation behavior observed in the individual tests.

E.4.8 Test System Operation

The reaction vessels and the gas manifold system (Figure E.1.) used for the gas-generation tests are similar to those describe in the previous work with K Basins Sludge Delegard et al. (2000) (Series I), Bryan et al. (2001) (Series II), and Schmidt et al. (2003) (Series III). Each vessel has a separate pressure transducer on the gas manifold line. The entire surface of the reaction system exposed to the sludge sample is stainless steel, except for a copper gasket seal between the flange and the top of the reaction vessel. Temperatures and pressures are recorded every 10 s on a Campbell Scientific CR10 data logger; the data are averaged every 20 min and saved in a computer file. Temperature and pressure data are also manually logged once each working day.

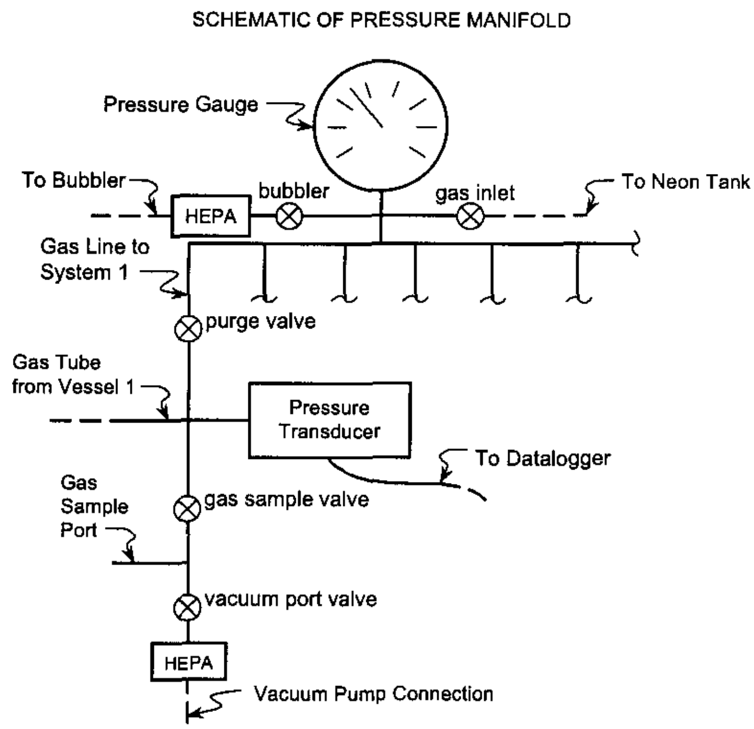

Figure E.1. Layout of Gas Pressure Measurement and Gas Sample Manifold Used in Gas-Generation Tests (includes details for one of 6 systems)

Figure E.2 illustrates a reaction vessel and shows where the thermocouples are placed inside and outside the vessel. For the gas-generation testing, each vessel was wrapped in heating tape and insulated. Two thermocouples were attached to the external body, one for temperature control and one for over-temperature protection. Two thermocouples were inserted through the flange. The thermocouple centered in the lower half of the vessel monitored the temperature of the liquid phase; the one centered in the upper half monitored the gas phase temperature within the reaction vessel. The reaction vessels were placed in a hot cell and connected by a thin (0.0058-cm inside diameter) stainless steel tube to the gas manifold outside the hot cell. A stainless steel filter (2-μm pore size, Nupro) protected the tubing and manifold from contamination. A thermocouple was attached to this filter as well.

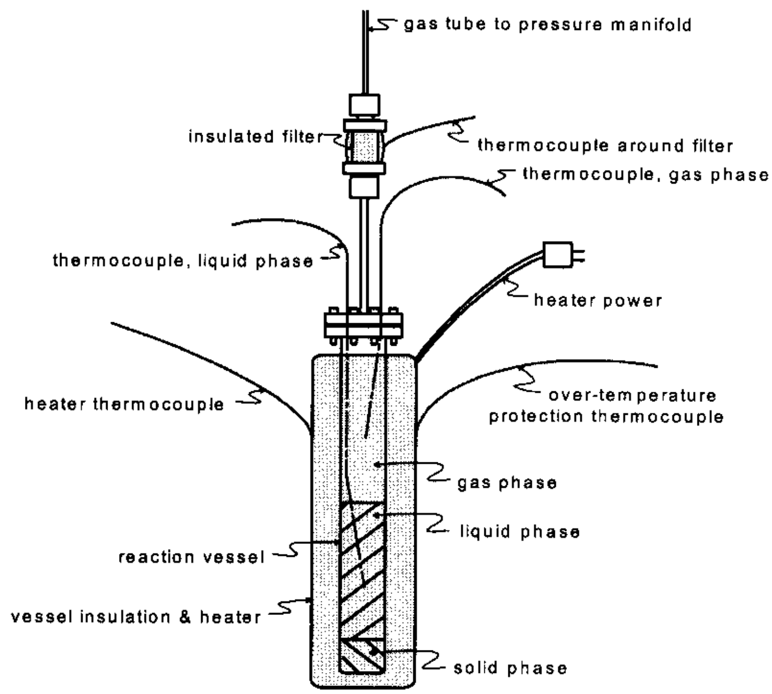

Figure E.2. Schematic of Reaction Vessel

An atmospheric pressure gauge was attached to the data logger. The pressure in each system was the sum of atmospheric pressure and the differential pressure between the system internal and external (atmospheric) pressures. An inert cover gas (neon) was required to identify product gases and understand the chemical reactions occurring in the settled sludge. The neon gas used was analyzed independently by mass spectrometry and determined to contain no impurities in concentrations significant enough to warrant correction.

At the start of each run, each system was purged by at least eight cycles of pressurizing with neon at 45 psi (310 kPa) and venting to the atmosphere. The systems were at atmospheric pressure, about 745 mm Hg (99.3 kPa), when sealed. The vessels then were heated, and the temperature set points were adjusted to keep the material within 1°C of the desired liquid phase temperatures.

As necessary during the testing and at the end of each reaction sequence, the vessels were allowed to cool to ambient temperature and then a sample of the gas was taken from the headspace for mass spectrometry analysis. Gases in the reaction system were assumed to be well mixed. The metal gas collection bottles were equipped with a valve and had a volume of approximately 75 mL. After the bottle was evacuated overnight at high vacuum, it was attached to the gas sample port. After the sample was collected, the reaction vessel was purged again with neon. The compositions of the gas phase of each reaction vessel during selected gas samplings were analyzed by PNNL using analytical procedure PNNL-98523-284 Rev. 0.

E.5 KE NLOP Gas-Generation Testing Results

In each test, gas-tight reaction vessels were loaded with KE NLOP sludge and waste forms, the gas space purged with neon, and the loaded vessels heated to the selected temperature. Gas samples were taken from the vessels in accordance with the test plan. Gas-generation rates were determined for each gas sample, based on the heating time, the gas composition, the total gas quantity in the system from which the sample was taken, and the sludge mass present in each reaction vessel.

E.5.1 Gas-Generation Profile for Sludge Only Tests

The gas-generation profiles (g-mol of gas generated/kg-settled sludge as a function of reaction time) for the initial test interval of the sludge only tests are provided in Figure E.3. Test 1 and 2, NLOP-U1 and U-2 are duplicate tests conducted at 95°C. Test 3, NLOP-Control, was conducted at 60°C.

E.5.2 Results of Gas Sample Analysis for Sludge Only Tests

Based on the mass spectrometry analysis of the gas sample, carbon dioxide (CO_2), hydrogen (H_2), and methane (CH_4) and higher hydrocarbons were observed and quantified. Detailed descriptions of gas generating (and gas consuming) reactions in K Basin sludge are provided in Delegard et al. (2000), Bryan et al. (2001), and Schmidt et al. (2003).

The quantities of gas produced and consumed during the initial interval for each test are presented in Table E.2. The gas product was ~95% CO_2 for all three tests. Hydrogen comprised 5.07% 4.17%, and 4.93% of the product gas for NLOP-U1, NLOP-U2, and NLOP-Control tests, respectively. Hydrocarbons comprised the balance of the gas production, and N_2 and O_2 were consumed in all three tests. No indications of the presence of fission product gases were found. For comparison, the quantities of gas produced and consumed for the 1999 sample, FE-3 are provided. While the NLOP-U1, NLOP-U2, and NLOP-Control reaction vessels each contained about 50 g of settled sludge, the FE-3 test was conducted with 21 g of settled sludge.

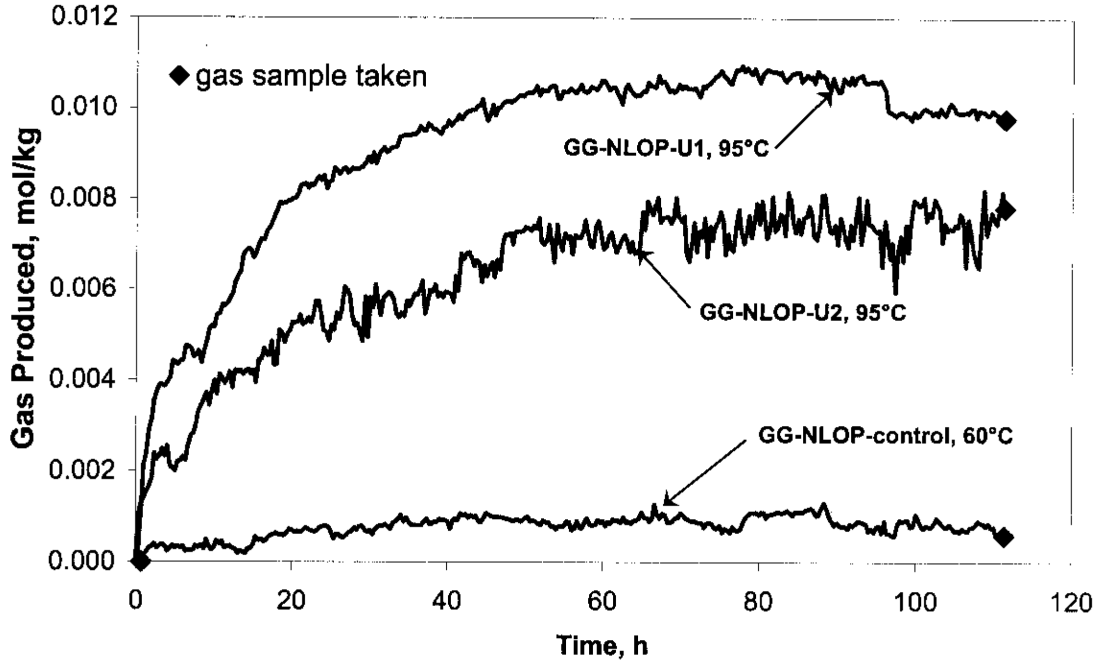

Figure E.3. Total Gas Generation from NLOP-U1 and NLOP-U2 at 95°Cand NLOP-Control at 60°C

The gas sample compositions from the NLOP-U1, NLOP-U2, and NLOP-Control tests are given in Tables E.3 through E.5. Gas samples were analyzed by mass spectrometry. The compositions of the generated gases (derived from the compositions of sampled gas by excluding the neon cover gas, argon, and trace nitrogen and oxygen from atmospheric contamination) are presented and are indicated by shading. For example, if analysis found 80% Ne, 5% CO_2, and 15% H_2, the composition of gas formed by excluding Ne would be 25% CO_2 and 75% H_2.

The presence of argon in the gas samples was used to indicate atmospheric contamination (air), since it is not present in the cover gas and is not produced by the sludge. Nitrogen could have been generated or consumed by the sludge or could have come from atmospheric contamination. The percent nitrogen actually generated or consumed is given by the percent nitrogen found minus 83.6 times the percent argon in the sample (the ratio of nitrogen to argon in dry air is 83.6). The percent oxygen actually generated or consumed in the samples may be calculated in a method similar to nitrogen. The sum of all percents for a test interval in Table E.3 may not be exactly 100%, because the values were rounded. The uncertainties in all the entries in these tables are approximately plus or minus 1 in the last digit.

Individual gas-generation rates are calculated based on the total moles of gas produced (Figure E.3) the generated gas compositions (Tables E.3 through E.5), and the initial test interval time. Tables E.6 through E.8 show the gas-generation rates derived in this manner for the initial test interval.

Table E.2. Net and Cumulative Quantities of Gas Evolved for FE-3 NLOP-U1, NLOP-U2, and NLOP-Control

Gas	Gas Quantities, moles, at Sampling Times							
	FE-3		GG-NLOP-U1		GG-NLOP-U1		GG-NLOP-Control	
	493.00 h	**970.00 h**	**111.33 h**		**111.33 h**		**111.33 h**	
CO_2	8.52E-05	8.31E-05	4.30E-04		4.22E-04		7.06E-05	
Cumulative	8.52E-05	1.68E-04	4.30E-04		4.22E-04		7.06E-05	
H_2	2.53E-07	3.06E-07	2.30E-05		1.84E-05		3.68E-06	
Cumulative	2.53E-07	5.58E-07	2.30E-05		1.84E-05		3.68E-06	
N_2	-7.11E-06	1.19E-06	-7.16E-06		-1.98E-05		-1.60E-05	
Cumulative	-7.11E-06	-5.92E-06	-7.16E-06		-1.98E-05		-1.60E-05	
O_2	-4.03E-06	-7.81E-07	-7.73E-06		-9.08E-06		-6.97E-06	
Cumulative	-4.03E-06	-4.81E-06	-7.73E-06		-9.08E-06		-6.97E-06	
CH_4	5.42E-08	5.39E-08	3.80E-07		4.34E-07		1.84E-07	
Cumulative	5.42E-08	1.08E-07	3.80E-07		4.34E-07		1.84E-07	
C_2H_x	1.08E-07	8.99E-08	2.53E-07		4.96E-07		2.45E-07	
Cumulative	1.08E-07	1.98E-07	2.53E-07		4.96E-07		2.45E-07	
$\geq C_3H_x$	9.03E-08	8.99E-08	6.33E-08		4.34E-07		6.14E-08	
Cumulative	9.03E-08	1.80E-07	6.33E-08		4.34E-07		6.14E-08	
Σ C_yH_x C	5.57E-07	5.19E-07	1.09E-06		2.80E-06		8.70E-07	
Cumulative	5.57E-07	1.08E-06	1.09E-06		2.80E-06		8.70E-07	
^{83}Kr								
Cumulative	0.00E+00	0.00E+00	0.00E+00		0.00E+00		0.00E+00	
^{84}Kr								
Cumulative	0.00E+00	0.00E+00	0.00E+00		0.00E+00		0.00E+00	
^{85}Kr								
Cumulative	0.00E+00	0.00E+00	0.00E+00		0.00E+00		0.00E+00	
^{86}Kr								
Cumulative	0.00E+00	0.00E+00	0.00E+00		0.00E+00		0.00E+00	
Σ Kr	0.00E+00	0.00E+00	0.00E+00		0.00E+00		0.00E+00	
Cumulative	0.00E+00	0.00E+00	0.00E+00		0.00E+00		0.00E+00	
^{130}Xe								
Cumulative	0.00E+00	0.00E+00	0.00E+00		0.00E+00		0.00E+00	
^{131}Xe								
Cumulative	0.00E+00	0.00E+00	0.00E+00		0.00E+00		0.00E+00	
^{132}Xe								
Cumulative	0.00E+00	0.00E+00	0.00E+00		0.00E+00		0.00E+00	
^{134}Xe								
Cumulative	0.00E+00	0.00E+00	0.00E+00		0.00E+00		0.00E+00	
^{136}Xe								
Cumulative	0.00E+00	0.00E+00	0.00E+00		0.00E+00		0.00E+00	
Σ Xe	0.00E+00	0.00E+00	0.00E+00		0.00E+00		0.00E+00	
Cumulative	0.00E+00	0.00E+00	0.00E+00		0.00E+00		0.00E+00	

Table E.3. Gas Analyses for GG-NLOP-U1 at 95°C

Run Sys –3	Temp. °C	Ne	Ar	H_2	CO_2	CH_4	C_2 HC	$C_{>2}$ HC	N_2	O_2	Kr	Xe	Time, h
1	95	91.8	0.013	0.364	6.8	0.006	0.004	0.001	0.890	0.147	<0.001	<0.0001	111.3
27KE15				5.07	94.77	0.084	0.056	0.014	-1.578	-1.702	<0.014	<0.0014	
Blank entries are below detection limits. Shaded values denote the generated gas composition (i.e. neon cover gas contribution deducted).													

Table E.4. Gas Analyses for GG-NLOP-U2 at 95°C

Run Sys –4	Temp. °C	Ne	Ar	H_2	CO_2	CH_4	C_2 HC	$C_{>2}$ HC	N_2	O_2	Kr	Xe	Time, h
1	95	92.5	0.009	0.297	6.8	0.007	0.008	0.007	0.350	0.033	<0.001	<0.0001	111.3
27KE15				4.17	95.52	0.098	0.112	0.098	-4.478	-2.057	<0.014	<0.0014	
Blank entries are below detection limits. Shaded values denote the generated gas composition (i.e. neon cover gas contribution deducted).													

Table E.5. Gas Analyses for GG-NLOP-Control at 60°C

Run Sys –5	Temp. °C	Ne	Ar	H_2	CO_2	CH_4	C_2 HC	$C_{>2}$ HC	N_2	O_2	Kr	Xe	Time, h
1	60	98.5	0.007	0.060	1.15	0.003	0.004	0.001	0.241	0.021	<0.001	<0.0001	111.3
27KE15				4.93	94.41	0.246	0.328	0.082	-21.397	-9.324	<0.014	<0.0014	
Blank entries are below detection limits. Shaded values denote the generated gas composition (i.e. neon cover gas contribution deducted).													

Table E.6. Gas-Generation Rates from GG-NLOP-U1 at 95°C

Run	Temp.	Gas-Generation Rate, moles/kg-day									
	°C	H_2	CO_2	CH_4	C_2 HC	$C_{>2}$ HC	N_2	O_2	Kr	Xe	Time, h
1	95	8.8E-5	1.6E-3	1.4E-6	9.6E-7	2.4E-7	-2.7E-5	-2.9E-5			111.3
Blank entries are below detection limits.											

Table E.7. Gas-Generation Rates from GG-NLOP-U2 at 95°C

Run	Temp.	Gas-Generation Rate, moles/kg-day									
	°C	H_2	CO_2	CH_4	C_2 HC	$C_{>2}$ HC	N_2	O_2	Kr	Xe	Time, h
1	95	7.3E-5	1.7E-3	1.7E-6	2.0E-6	1.7E-6	-7.8E-5	-3.6E-5			111.3
Blank entries are below detection limits.											

Table E.8. Gas-Generation Rates from GG-NLOP-Control at 60°C

Run	Temp.	Gas-Generation Rate, moles/kg-day									
	°C	H_2	CO_2	CH_4	C_2 HC	$C_{>2}$ HC	N_2	O_2	Kr	Xe	Time, h
1	60	1.4E-5	2.7E-4	7.1E-7	9.5E-7	2.4E-7	-6.2E-5	-2.7E-5			111.3
Blank entries are below detection limits.											

E.6 References

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Appendix F

Waste-Form Preparation and Testing

Appendix F: Waste-Form Preparation and Testing

Waste-form preparation and testing was performed in the 325 Laboratory. Tests with simulated sludge occurred in a non-radioactive laboratory and KE NLOP sludge tests occurred in the glovebox of Room 528. Three waste forms were prepared from KE NLOP settled sludge and KE NLOP supernatant solution to evaluate preparation methods and to understand the waste forms' performance and qualities. The work proceeded according to the Test Instruction "Preparation of KE NLOP Waste Forms," 46857-TI03. After preparation and in-glovebox testing, the waste forms were loaded out of the glovebox for gas-generation testing under the Test Instruction "KE NLOP Sludge Gas Generation Testing," 46857-TI04.

Based on evaluations given in the Test Plan ("Bench-Scale Test Plan to Demonstrate Production of WIPP-Acceptable KE-NLOP Sludge Waste Forms at the 325 Building," December 2003), three waste forms were prepared. The names and general descriptions of the waste forms are shown in Table F.1.

Table F.1. KE NLOP Waste Forms

Waste-Form Name	Description
NLOP-Moist	~50 g of as-settled sludge, drained of liquid
NLOP-Gt	~50 g of as-settled sludge and ~25 g of supernatant solution, blended and cured in grout
NLOP-Nochar	~50 g of as-settled sludge and ~25 g of supernatant solution, blended with Nochar Acid Bond 660

Preparation of the Drained Waste Form NLOP-Moist

The waste form NLOP-Moist was prepared with the aim to obtain a concentrated (low-volume) waste that had no drainable liquid. The waste form was prepared by weighing a representative aliquot of the KE NLOP settled sludge (52.87 g) into a 50-mL plastic centrifuge cone. A stack of two filter papers were placed in a weighing boat and the boat and papers were weighed. The open centrifuge cone was held in the vertical position and the filter papers and boat were placed on the open end of the cone with the papers in contact with the cone. With the boat/filter/cone held tightly together, the assembly was inverted with the cone resting on the filter papers within the boat. The boat was placed on a clean and stable surface and the free liquid allowed to pass through the filter.

The filter papers prevented sludge solids from leaving the cone while acting as a wick to draw solution from the sludge where it could evaporate from the margins of the papers. The boat/filter/cone was kept in the inverted position for two days but seemed to be well drained after one day. The centrifuge cone with drained solids was re-weighed (28.92 g) after two days and the volume of the tapped solids measured (20 mL) to determine final form density (1.45 g/mL).

The drained sludge waste form NLOP-Moist then was ready for transfer to a vessel for gas-generation testing.

Preparation of the Grouted Waste Form NLOP-Gt

Consultation with PNNL technical experts Ryan Lokken and Larry Bagaasen, review of technical literature, and a few preliminary tests using simulated KE NLOP sludge and supernatant solution (21 wt% sand in water) were done to develop grout formulations to solidify KE NLOP settled sludge with 50 wt% (with respect to settled sludge) of accompanying decant water. The goals of the consultation and laboratory work with simulants were to find a formulation producing a "workable" (e.g., readily mixed) slurry that would set under air-tight conditions and produce a solid form yielding no "bleed water" (free liquid). Simple formulations were preferred.

The consultations and findings showed that Portland Type I, II, or I/II cement is suitable as the cement component and that bleed water can be controlled by use of bentonite (mineral name montmorillonite) or attapulgite (mineral name palygorskite) additives. Bentonite works by adsorbing water between its plate-like particles. Attapulgite works by adsorbing water between its needle-shaped particles. Attapulgite is preferred for grouts having high salt loading because it maintains is dispersibility whereas the inter-plate spaces between the bentonite particles collapse in salty environments causing bentonite to lose its ability to hold water.[a] Though both bentonite and attapulgite were tested, bentonite was selected for testing with KE NLOP sludge because the KE NLOP sludge has little salt and because bentonite is an additive familiar to WIPP.

Prior experience and laboratory tests showed that a water/cement ratio of about 0.5 produces an easily-mixed slurry. However, this blend produces significant bleed water. Higher cement fractions in the grout become increasingly difficult to mix and still yield appreciable bleed water (note – the WIPP waste form must have no free liquid). Incremental bentonite additions to 0.5 ratio water/cement slurries were tested for workability and free liquid in the set product. It was found that a consistency that would hold a peak when the mixer was withdrawn but was not so thick that it would ball-up produced a grout that set under closed conditions and yielded no bleed water. The amount of bentonite added proved to be about 9 wt% of the Portland cement used.

Based on these findings, the NLOP-Gt waste form was prepared by adding a weighed amount (50.40 g) of well-mixed KE NLOP settled sludge composite to a plastic mixing beaker, adding supernatant solution (24.73 g) in the amount of half of the weight of settled sludge, and then adding Portland type I/II cement in an amount equal to twice the mass of the water contained in the combined settled sludge (62 wt% water) and supernatant (112.00 g). The cement/sludge/supernatant ingredients were mixed thoroughly until the mixture was homogeneous. While stirring continued, bentonite (a powder) then was slowly sprinkled in. The adding and stirring continued episodically until the mixture was thick but not lumpy. The stirring continued for a full three minutes to ensure homogeneity. The amount of bentonite added was 6.60 g or 6 wt% of the added cement.

The first portion of the sludge/cement/bentonite mixture was cast into a tare-weighed 30-mm diameter by 110-mm long polyethylene container (about 70 mL volume). The remainder was cast into a tare-weighed 50-mL centrifuge cone. The mixture was thick and would not pour but had to be transferred by spatula. Both vessels were capped shut after the grout was transferred and the containers re-weighed. The net amounts of grouted waste were 142.61 g in the polyethylene container and 47.75 g in the centrifuge cone,

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(a) Tallard G. 1997. "Self-Hardening Slurries and Stable Grouts from Cement-Bentonite to IMPERMIX®," pp. 142-149. In: *Barrier Technologies for Environmental Management: Summary of a Workshop*, National Academies Press, National Academy of Sciences, Washington, D.C.

accounting for 190.36 g of the total 193.73 g of ingredients. The ~3 g of residue was lost on the mixing vessel and tools.

The casting in the centrifuge cone was tapped down to remove voids and allowed to set. The volume of this casting was 24.5 mL (after set though no shrinkage/expansion was observed), yielding a grouted waste-form density of 1.95 g/mL. The other casting, prepared for gas-generation testing, also was tapped down to remove voids. After about one hour, before the cement had set, a ~3-mm diameter hole was pushed axially into the wet grout using a screwdriver shaft. The intention was to form a well in the grouted form to accommodate a thermocouple for the gas-generation test. The grouted forms were examined after one day of curing and found to be solid and to contain no free liquid.

Each grouted form lost only 0.02-0.05 g on curing. The hole in the grouted form evidently had filled-in below about 3-cm depth when the screwdriver was withdrawn from the wet grout. The hole was deepened by use of a twist bit drill after two days of curing. It was observed during the drilling that the grout was hard though not fully cured, but with no muddiness or free moisture. The polyethylene container was cut from the casting and the prepared form NLOP-Gt was ready for gas-generation testing. The net weight of the grouted form after drilling was 138.26 g and contained 71.4% of the settled sludge and supernatant water used in the original mixture.

Preparation of the Nochar Waste Form NLOP-Nochar

The polyacrylic water sorbent Acid Bond 660 offered by Nochar is a dry fine granular powder that has been used to absorb aqueous solutions in wastes destined for WIPP. The Nochar addition absorbs the free liquid and allows the waste to achieve the criterion of having no drainable liquid. The Nochar capacity to absorb water is pH-dependent with higher absorption found at higher pH. The pH of the KE NLOP settled sludge is about 8.3 and that of the supernatant liquid is about 7.5, well within the range of optimum applicability of Nochar Acid Bond 660.

Based on vendor literature (Nochar, Inc., www.nochar.com), Nochar solidification agents have been tested and proven in over 150 waste streams (including stabilization of TRU-containing aqueous/sludge waste streams for ultimate disposal to WIPP). Stability tests performed on Nochar include paint filter testing, freeze/thaw testing, vibration testing, and radiation stability testing (90 Mrad—gamma/cobalt source). Due to project time constraints (i.e., insufficient time for independent testing), the vendor information on Nochar stability and its acceptance by WIPP served as the technical basis for judging the long-term stability for the Nochar/KE NLOP sludge waste form.

Preliminary tests with simulated KE NLOP sludge having 50 wt% additional water (a sand-water mixture containing 21 wt% sand) were performed to understand Nochar behavior and judge the quantity of Nochar required to eliminate drainable liquid. The addition of about 6 wt% Nochar, with respect to water, or about 4.5 wt% Nochar, with respect to the total sludge-plus-water mass, was sufficient to form a gelled semi-solid of cooked Cream-of-Wheat consistency. The water absorption was rapid, occurring in 1 to 2 minutes. The product had a bulk density of 1.03 g/mL.

Based on this information, the waste form NLOP-Nochar was prepared. First, a 53.83 g aliquot of the KE NLOP sludge composite and 24.35 g of supernatant solution (about 68 mL total volume) were combined in a 125-mL bottle. Then, 2.95 g of Nochar Acid Bond 660 was added, the bottle capped, and the contents mixed by shaking. This method of mixing was used to eliminate waste-form losses incurred by use of a stirrer. After shaking, the bottle was opened and the product observed. No free liquid was seen and the contents had a gelled springy consistency but with much open volume (air space), caused by the mode of mixing, that could not be decreased by tapping. The product was left overnight and no free liquid was seen. A further day of storage still showed no free liquid. The total volume of the void-filled product was about 120 mL yielding a bulk density of 0.68 g/mL.

Properties of the Various KE NLOP Waste Forms

The compositional and volumetric properties of the KE NLOP waste forms (NLOP-Moist, NLOP-Gt, and NLOP-Nochar), and the test parameters, are presented and compared in Table F.2. The volume increases or decreases (expansion factors) incurred in going from the settled sludge to the prepared waste form are given in Table F.2. For example, the tests show that the drained sludge product, NLOP-Moist, is only about half (0.47) of the volume of the starting sludge. In contrast, the grouted and Nochar waste forms, which also included additional supernatant solution, added to the final waste-form volumes such that the grouted and Nochar product expansion factors were 2.45 and 1.82, respectively.

Table F.2. KE NLOP Waste-Form Properties

Parameter	Waste Form		
	NLOP-Moist	NLOP-Gt	NLOP-Nochar
Waste Composition			
KE NLOP settled sludge mass, g	52.87	50.40	53.83
KE NLOP settled sludge volume, mL	42.6	40.6	43.4
KE Basin supernatant solution, g	0	24.73	24.35
Total feed waste mass, g	52.87	75.13	78.18
Total feed waste volume, mL	42.6	65.4	67.8
Additive			
Portland type I/II cement, g	--	112.00	--
Bentonite, g	--	6.60	--
Nochar Acid Bond 660, g	--	--	2.95
Property			
Final waste-form volume, mL	20	99.3	79 (packed) / 120 (loose)
Final waste-form mass, g	28.92	193.73	81.13
Final waste-form density, g/mL	1.45	1.95	1.03 (packed) / 0.68 (loose)
Expansion factor, settled sludge → final waste form	0.47	2.45 [a]	1.82 (packed) [b] / 2.76 (loose) [b]
Expansion factor, sludge & supernate → final waste form	--	1.52	1.17 (packed) / 1.77 (loose)

[a] The expansion factors apply to the feed settled sludge for sludge plus supernatant water formulations; water (e.g., from supernatant solution) still required for grouted waste formulation.
[b] The expansion factors apply to the feed settled sludge for sludge plus supernatant water formulations; the actual expansion factors for sludge-only (supernatant-free) formulations likely are lower and approach 1.17 (packed) / 1.77 (loose). Testing is required to confirm this behavior.